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Frontispiece

Barohoini Natural Bridge (Piute for rainbow); northwest of Navajo Mountain, southern Utah. Work of erosion in LaPlata Sandstone. Height 309 feet; width between abutments 278 feet; causeway at top 33 feet wide.

(Photo by H. E. Gregory.)

INTRODUCTORY GEOLOGY

FOR USE IN
UNIVERSITIES, COLLEGES, SCHOOLS OF SCIENCE, ETC.
AND FOR THE GENERAL READER

PART I

PHYSICAL GEOLOGY

BY

LOUIS V. PIRSSON

Late Professor of Physical Geology in the Sheffield Scientific School of Yale University

PART II

OUTLINES OF HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

Professor Emeritus of Paleontology in Yale University and of Historical Geology in the Sheffield Scientific School

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1924

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PREFACE TO PART I, SECOND EDITION

PREFACE TO THE SECOND EDITION

A new edition of a textbook, especially in a scientific subject like Geology, in which fresh material is constantly appearing, demands no particular explanation. The plan and scope of the work remains unchanged, and in the revision and the addition of new matter in many places the effort has been made to keep the length of the work essentially the same.*

The author is indebted to various friends and correspondents for corrections, helpful criticisms, and suggestions for betterments, to whom he desires to extend his thanks and appreciation for the interest they have shown and the pains they have taken in the matter. He would like to mention in this connection Mr. C. K. Needham, Dr. H. H. Robinson, who redrew several figures, and especially Prof. Douglas W. Johnson of Columbia University for many valued suggestions.

In like manner his thanks are due also to his colleagues, Professor H. E. Gregory, Professor A. M. Bateman and the late Professor Joseph Barrell.

Owing to illness, the revision of the proof has been kindly undertaken by Professor Schuchert and Miss Clara Mae Le Vene.

L. V. PIRSSON.

SHEFFIELD SCIENTIFIC SCHOOL OF YALE UNIVERSITY,
NEW HAVEN, CONN.,
May, 1919.

FROM THE PREFACE TO THE FIRST EDITION

For many years the author of this book has been called upon to give the first course in Physical Geology to large classes of students, among whom are to be found those pursuing courses leading to professional work in various branches of Engineering, Mining, Metallurgy, Forestry, Chemistry, etc., and in Geology itself, to whom therefore the subject has a direct technical value or serves as a basis for further technical studies. Naturally these students find a first general course in Physical Geology one of cultural interest as well.

In the pursuit of this work the writer has long felt the need of a

* In the present reprinting of this edition, Chapter XVI, on Ore Deposits, has been rewritten by Professor A. M. Bateman.

textbook which, while presenting the broad facts and principles of the science from the latest viewpoint, should have a character somewhat different, and a balance more even in the subject matter composing it, than is to be found in available texts.

Although original matter or views of problems have been incorporated in places, it is obvious that the preparation of a work of this nature must mainly be one of selection of the subject matter from published material. It would be impossible to give the greatly varied sources from which it has been drawn, but it may be mentioned that the general treatises of Dana, Geikie, Chamberlin and Salisbury, Haug, Suess, and others, together with the wealth of material embodied in the reports and bulletins of the United States Geological Survey, have been freely used, as well as other works in special fields too numerous to mention.

For efficient help, freely given, in the reading and preparation of different parts of the text, the author wishes to render grateful acknowledgment to his friends and colleagues, Professors J. P. Iddings, J. D. Irving, W. E. Ford, and especially to Professor Joseph Barrell, whose criticism and advice were of the greatest service.

In the matter of illustrations the writer desires to express his obligations especially to Dr. George Otis Smith, Director of the United States Geological Survey, who placed at his disposal its great mass of photographic material, the proper credit for these photographs being given in each case; to Mr. J. J. H. Teall, recent Director of the Geological Survey of Great Britain; to Professor G. P. Merrill of Washington, D. C.; to Professor J. E. Talmage of Salt Lake City; to Mr. G. W. Grabham of Khartoum, and to many other friends whose names are credited in each case.

L. V. PIRSSON.

SHEFFIELD SCIENTIFIC SCHOOL OF YALE UNIVERSITY,
NEW HAVEN, CONN.,
Dec., 1914.

PREFACE TO PART II

Ever since 1915, when my Text-book of Historical Geology first appeared, there has been a demand for a small book treating of the earth's history, to be used in colleges where Geology is taught to Freshmen, or where the curriculum does not allow time enough for an adequate presentation of the subject. On the appearance of the enlarged second edition, this demand seemed likely to become insistent, and since the history of the earth is so wonderfully interesting and the basis from which all studies of nature and human philosophy should proceed, I decided to try to meet it. Therefore, while wintering at Tucson, Arizona, I spent some time selecting from the large book such material as seemed to embody the limit of information necessary to an adequate understanding of the rudiments of the earth's history. This rough manuscript, which totalled some 300 printed pages, I sent to my secretary, Miss Clara Mae LeVene, who has aided me in the preparation of both editions of the larger book, telling her to rewrite it in places, if necessary, but above all, to do what I could not, namely, to cut it down to about 200 pages. On my return to New Haven, I found that she had so condensed and rearranged the book as to bring it down to 225 pages, without, as it seemed to me, omitting any of the essential information. I then took the greatly reduced manuscript, and while readjusting it, learned from what had already been done how to cut out still more! The residue is the Outlines of Historical Geology which forms Part II of the present volume, and which we hope will be acceptable to those teachers who have asked for a shorter book on which to base their course in the subject.

I am deeply grateful to Miss LeVene for her great assistance, and my thanks are also due to my colleague, Doctor Carl O. Dunbar, who teaches Historical Geology at Yale University, and at whose suggestion some of the changes have been made.

CHARLES SCHUCHERT

PEABODY MUSEUM OF YALE UNIVERSITY,
NEW HAVEN, CONNECTICUT,
June, 1924

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PART II

OUTLINES OF HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

OUTLINES OF HISTORICAL GEOLOGY

CHAPTER XVII

HISTORICAL GEOLOGY

Physical Geology, as we have learned in the first part of this book, deals with the architecture of the outer shell of the earth, and with the geological processes which have operated to bring it about. Historical Geology, on the other hand, studies the results achieved by these forces during the past geologic ages, presenting the procession of important events, physical and vital, that the earth is known to have gone through. It carries the history of the earth back of the human record, through millenniums whose only annals are written in the rocks and in the life of the past which they contain. This geologic history is, however, but an imperfect chronicle, abounding in omissions or alterations of record, due to vicissitudes which the rocks have suffered. Not even all the grander features are yet known, and of the detail but little, despite a century or more of study by geologists and paleontologists in all lands.

The keynote of all geologic history, whether of physical events or of life, is *change*. On the physical side, the earth has, we believe, progressed from a nebulous state to one with a more or less solid crust, which, by attaining more mass, developed the power of holding to itself an atmosphere, and then took from this atmosphere the water to fill its oceanic basins. Geologic time, properly speaking, begins when the earth has ceased to grow, and when the rain and the wind commence their ages-long task of wearing down the high places and transporting them into the low ones. The lands are altering slowly but continually, due not only to the work of these atmospheric agencies, but to adjustments taking place within the shrinking interior of the earth. The oceans periodically spread over them as shallow seas, and the floods are as often withdrawn, but *there is no general interchange in position between the continents and the basins of the oceans.* Great and grand ranges of mountains are

raised many times near the borders of the continents, only to be broken up little by little and spread out as sheets of sediment over the bottoms of the adjacent seas. "Rocks fall to dust and mountains melt away." Originally the continents were vastly larger and trended east and west; now they strike north and south, due to vast founderings of lands into the depths of the oceans. The oceanic basins, in other words, grow steadily larger at the expense of the lands.

Just as the surface of the earth is in a continual state of slow change due to internal alterations and gravity, so in consequence must be the atmosphere, since it results from the earth's exhalations. When the lands are high, igneous activity is greatest, and deep-seated rock materials are injected into the earth's crust, lavas and volcanic ashes are spread over it, and new water vapor and gases are added to the atmosphere.

All this crustal and atmospheric instability results in changing environments for the plants and animals, in greatest degree among the organisms of the lands, and least so in the oceanic realms. Life, beginning probably in the seas, at some early time when they first became fit for its habitation, developed into an astonishingly great variety of marine invertebrates, and out of one of these stocks came the little lancelet, "the prophecy of a fish." Spreading up the rivers, these lancelets doubtless developed into the fresh-water fishes, which are present early in the fossil record. Rivers, however, are treacherous abodes for life, since they are dependent upon rains and humid climates, hence in places the fishes found their water homes drying up around them, and were forced out upon the lands, there to start the long upward evolution toward the higher vertebrates. This evolution has not, however, been a steady upward process, but through ceaseless trial and failure and the consequent weeding out of the less fit, there arise ever more perfected organisms, with greater and greater mentality, to culminate finally in man.

CHAPTER XVIII

THE CHANGING ASPECT OF THE EARTH'S SURFACE

As we saw in the introductory chapter, one of the greatest truths of Geology is that the earth's surface is continually undergoing change. The oceanic basins and the continents are now generally held to have been in the main, although not at all in detail, permanent features of the earth's surface since very early in its history. During the long course of geologic time, the oceans have overflowed the lands in recurring cycles of advance and retreat, and over areas varying from small overlaps along the borders to 50 per cent of the interior portions of the continents, but there has been no complete interchange between them. Geologists generally agree that the oceanic basins are vast sinking fields because of the heavier materials beneath them, and speak of them as *negative areas*, because the sum of their crustal movements is downward. The continents, on the other hand, are rising masses of lighter rocks, called *positive areas*, because the sum of their movements is upward. In preparation for our study of the interrelationship of these topographic features, we shall examine each of them a little more in detail.

Continents. — Dana defines a continent as " a body of land so large as to have the typical basin-like form — that is, independent mountain chains on either side of a low interior." In North America, for example, the Pacific mountains face the Pacific Ocean, the narrower Appalachians margin the continent on the Atlantic side, and between the latter and the Rocky Mountains lies the vast continental basin.

The continents occupy about 30 per cent of the earth's surface, or some 57,000,000 square miles, as against 70 per cent, or about 139,000,000 square miles, taken up by the oceans. To the north of the equator occur about three-fourths of the total land areas (42,000,000 square miles), grouped about the small Arctic Ocean. Accordingly the northern hemisphere is also known as the land hemisphere. Over the south pole lies the large and high continent Antarctica, and surrounding it is the Antarctic Ocean, whose waters continue with undefined boundaries far into the northern hemisphere as the Pacific, Atlantic and Indian oceans. The Pacific Ocean alone is greater by 10,000,000 square miles than all the lands combined.

Most of the present continents have been formed around ancient protuberances, the nuclear lands, "the primeval, immovable cornerstones of the earth" (Emerson). The word *shield* has been applied to them, because the two best known examples, the Canadian and Baltic masses, have the form of a depressed shield. *Nucleus* is, however, an older and a better term.

Fig. 312. — Stereographic map of the western hemisphere, showing North and South America, or the occidental lands, and Antarctica. The nuclear lands, or shields, indicated in outline: 1, Canadis; 2, Columbis; 3, Antillis; 4, Amazonis, including Guianis; 5, Platis.

There are at least thirteen of these ancient land masses, but we need mention here only those with which we are to be mostly concerned in this book: in North America, *Canadis*, *Columbis* and *Antillis*; in South America, *Guianis-Amazonis* and *Platis*. (See Fig. 312.)

These so-called nuclei were the first parts of the crust to rise permanently above the oceanic level. Their rocks are now more or

less decidedly deformed and changed, due to vast granite masses that welled up hot into the sediments and with them rose into either mountains or plains. Being the oldest surficial rocks, they have been longest subject to erosion, and in them we therefore look miles deeper than elsewhere toward the heart of the earth's crust. Time and time again the oceans spread as interior seas over great parts of these cornerstones, but only rarely have they been refolded into mountains. Thus in the course of geologic time they have been transformed through erosion and sedimentation into great interior plains that are more or less completely framed in by periodically rising highlands called borderlands (see p. 466).

Even though these ancient nuclei were constantly wearing away, for ages there was on them but little of soil and no life of any kind, and it was not until the greater part of their history had passed that the lowlands became scantily clad with a feeble vegetation. These primitive plants, developing into the ancient diversified floras, provided a food supply for animal life in turn. Of all the environments for life, that of the lands is the most trying, because of the constantly changing topography, and it was the struggle to meet these new conditions that made the land life the most significant factor in organic evolution, although life probably originated in the marine waters and is still there in greatest variety. With a food supply established on the lands, certain of the invertebrate stocks took up their abode here, the rivers became peopled with fishes, and in desert areas, due to the annual drying up of the streams, these finned vertebrates changed gills into lungs and transformed themselves into air-breathing amphibians, the progenitors of the later reptiles. Out of the reptilian world, after the flowering plants became dominant, upwelled the modern birds, mammals and man.

Oceans. — Oceans are the beginning and end of the rivers of the lands. The word ocean now has reference to the connected bodies of marine water that envelop the earth, of which there are five, Pacific, Antarctic, Atlantic, Indian, and Arctic. The mediterraneans are also to be considered as oceanic areas, since they are not only large but also very deep, though never so deep as the deepest parts of the oceans. They are, however, long and narrow and more or less widely enclosed by continents. The typical example is the Roman Mediterranean lying between Eurasia and Africa; it figures largely in Historical Geology and we shall have much to say about it under the name *Tethys* (Fig. 349).

The mean depth of the oceans is placed at 12,000 feet, and the volume of all the oceanic waters is said to be fifteen times greater

than the mass of land protruding above sea-level. If all the deeper parts of the oceans were filled by solid material up to the estimated mean depth, it is said that there would result a universal ocean, covering the entire earth to a depth of 1.5 miles. These facts are recited here not only to impress the student with the immense volume of water, but further to show, since the waters are mobile and cover nearly three-fourths of the earth's unstable surface, why it is that the oceans are enabled so readily to overflow the lands upon relatively small changes in the elevation of the crust. As the oceans are all connected, a movement of the bottom of any one basin affects the oceanic level in all, raising or lowering the strand-line everywhere simultaneously.

The upper reaches of the oceans provide a very favorable habitat for organisms, because in them the environmental conditions are much more constant than on the lands or in the seas. Their temperature and salinity are more or less equalized by the warm currents which the trade winds carry from the tropics against the eastern half of the continents, there to be deflected by the varying shapes of the lands; these currents also spread widely the minute or larval stages of the marine animal life. The plant life finds the sunlight which is essential to it as far beneath the surface as 600 feet. Due to these conditions, the sun-lighted water of the oceans teems with micro-life, consisting of the most primitive plants and animals, many of which are luminescent This, the plankton of oceanographers, has been described as "the pastures of the sea," since upon it all other oceanic life is directly or indirectly dependent. Even in death it rains into the deeps, there to feed the relatively few strange forms which have adapted themselves to the cold abyssal waters.

The oceans also furnish a home to myriads of fishes, and at times in the earth's history they have been dominated by great reptiles, none of which now survive. The highest class of vertebrates, the Mammalia, are represented in the present oceans by such forms as the whale and walrus.

Seas. — In general use, the word sea is interchangeable with ocean, but in Geology it is more often used in a restricted sense and in its original meaning. It appears to have originated with the peoples of northwestern Europe who were familiar with the North Sea and the Baltic Sea. These are marginal and inland bodies of marine water that in the main are under 300 feet in depth, and lie upon or within the continents; hence they contrast distinctly with the far deeper and larger mediterraneans and the abyssal oceans.

The marginal or *shelf seas* lie upon the borders of the continental platforms; examples are the North Sea, and the Yellow Sea of China.

Other marine waters connected with the shelf seas or oceans, but situated wholly within the continental platforms are called *epeiric seas.* Examples of these are Hudson Bay, the Gulf of St. Lawrence and the Baltic Sea (see p. 111 and Fig. 313). As a rule, these waters do not have the normal salt content of oceans (3.5 per cent), but are more or less freshened. In arid places they are, however, far more saline and at times pass into salt-depositing seas. It is the areas of these seas that have in times past experienced great changes through variations of sea-level, sometimes being more or less completely emptied of their water, or filled with sediments and turned into land.

The seas are the essential recorders of earth history. At present they occupy a little more than 5 per cent of the earth's surface, or about 10,000,000 square miles, but in the past they have flooded the North American continent variably to about one-half its areal extent. In fact, almost all of Stratigraphic Geology is a study of the sediments of epeiric seas, while it deals little with those of the shelf seas and scarcely at all with the ocean deposits or oozes. The deposits made on dry land, the continental deposits, are of scattering occurrence and are in addition frequently devoid of animal remains until we come to more modern geologic time. When remains of extinct land life are present, they are of marked import, but they lose their chronogenetic value the more one goes back into geologic time.

The seas are wholly transparent to the sunlight; accordingly they constitute the only marine area where the bottoms are more or less covered with ground-dwelling plants, and as the majority of animals feed upon such plants, their greatest abundance is in these waters. On the other hand, as the seas are adjacent to the lands, receive the rivers, and feel the full effect of the waves and tides, it is natural that they should vary greatly in temperature, salinity, bottom scour and sedimentation. Since the oceans are mobile, moreover, any movement within the earth's mass is reflected by them and causes the seas to become shallower or deeper, or even to be transformed into dry land. Because of these constant changes in the physical, chemical and organic environment, the epeiric and shelf seas are the scene of severe struggles among their inhabitants, and consequently are the principal areas of marine organic evolution. For this reason they are sometimes referred to as " the cradle of evolution." They are not only the regions of greatest abundance of

Fig. 313. — Lands (white), seas (dotted), and oceans (white). The areas of the shelf and epeiric seas are shaded in dots, and the largest relic seas are in solid black.

bottom-living life, or benthos, but also the ones from which all the other water bodies of the world have been colonized.

The life habituated to shallow water bottoms can, as a rule, spread only throughout the shallow seas and along the shelf seas bordering the continents, never across the deep and cold ocean bottoms. Nor can it spread directly across the ocean surface, and even during the floating larval state there is usually not time enough for it to be conveyed to the far away shelf seas. It is, however, transported far inland with the spread of these shallow seas.

Periodic Spread of the Oceans over the Lands. — The many changes which the geography of the earth has undergone are due mainly to the fact that the surface of the earth and the oceanic level are at times in decided motion: "ages and cycles of Nature in ceaseless sequence moving." These crustal oscillations are not caused by heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain as such during more or less long stretches of geologic time. Not only do the lands move up and down, but it is also now clear that the ocean bottoms are periodically more or less in motion. For these reasons, the oceanic level in relation to the continents is inconstant, and the marine waters spread over the continents. The movement of the ocean waters may be of small and narrow extent, due to local warpings of the surface, or may spread over areas of great magnitude, in consequence of marked crustal deformation and the filling of the oceans with land detritus.

It is now known that the oceans have spread periodically and more or less widely over the North American continent at least twenty times. In a broad way, it may be stated that the floods begin and end with shelf seas marginal to the continent and occupying between 1 and 5 per cent of the total areas of the continental platforms, the conditions thus being not unlike the present conditions of overlap; while the greatest inundations are of the interior or epeiric seas that cover from 12 to about 50 per cent of the continent. There is a certain amount of rhythm in these periodic movements, and this has been used, as we shall see in Chapter XXI, to divide the geologic sequence into systems of rocks or periods of time.

As the oceans and seas are all connected one with another, and are also the receivers of most of the land wash, it follows that a displacement of the strand-line anywhere, through any cause, must be transmitted to all marine waters. It has been calculated that if the present protuberant land masses were transferred to the oceans the general sea-level would be raised about 650 feet, and therefore much

of the North American continent would be flooded to a depth of at least 200 feet.

Under the waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists. It is therefore apparent why the major portion of the earth's chronology depends for its determination upon the marine sediments. These sediments, except in so far as they are later eroded, record the extent of the transgressions, and their physical character, something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their fossils, or entombed life, they establish not only the chronology from place to place, but the sequence of time everywhere on the earth as well.

The Changing Topography of North America

Our study of the rock records shows us that the continents are continually undergoing change; they are from time to time slightly and irregularly elevated or depressed over more or less extensive areas, while long and narrow tracts toward their margins slowly subside tens of thousands of feet. Later these subsiding tracts rise fairly rapidly into mountains, and are subsequently reëlevated time and again. Outside of the long and narrow tracts of subsidence are rising wide borderlands that furnish the sediments for the shallow seas of the sinking areas, and that once extended hundreds of miles into the oceans beyond the present shorelines. These crustal movements, along with erosion, were the primary causes for the changing topographic and geographic aspects of North America, which will now be taken up in greater detail.

Geosynclines (study Fig. 314). — As a result of the work in the Appalachians and other mountain regions, geologists long ago saw that mountains occur only in areas of greatest sedimentary accumulation. The rock formations in the Appalachian region are, for example, possibly ten times and certainly six times thicker than the equivalent deposits of the same seas in the Mississippi Valley. These thick sediments we now know were accumulated in narrow troughs or synclines that persisted as shallow seaways for long periods of geologic time. Such troughs were unstable areas of the earth's crust, sometimes subsiding and sometimes rising, and finally their great thicknesses of sediments were folded into mountains. To these unstable areas Dana gave the name of geosynclines, since they

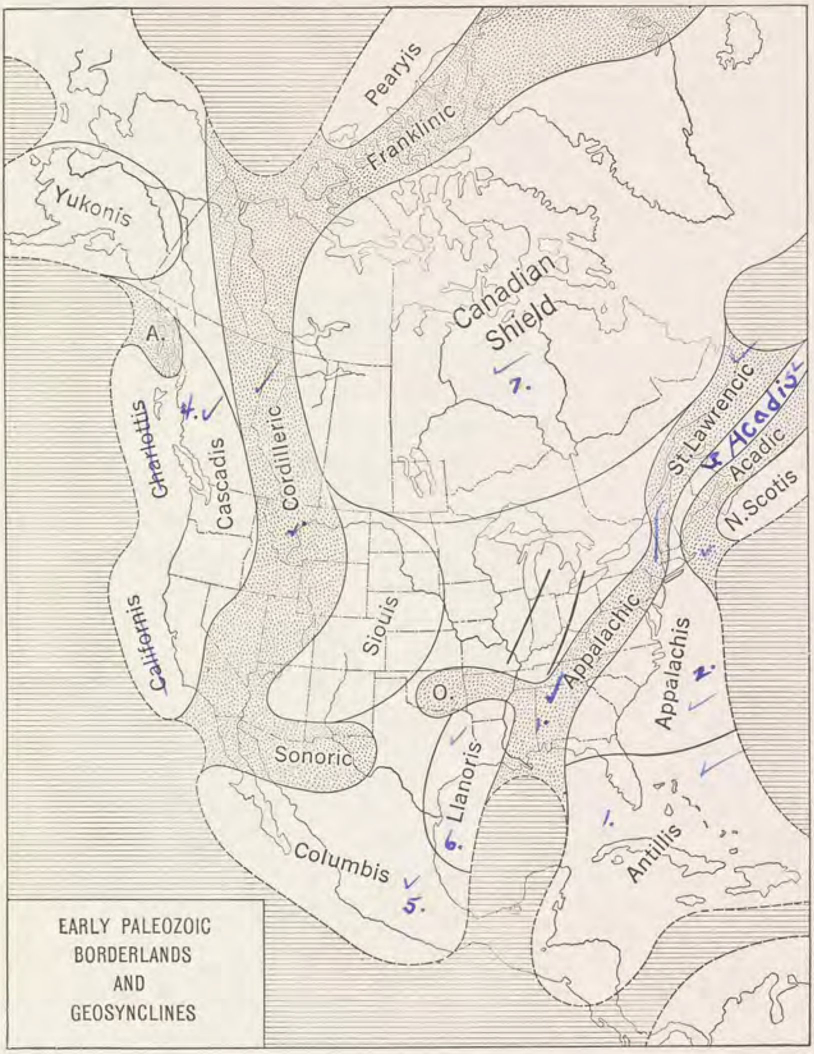

Fig. 314. — The North American borderlands, geosynclines, and medial or neutral area (Canadian Shield and Siouis) of earlier Paleozoic time. *A* = Alexandric embayment; *O* = Ouachitic embayment. The same relations of epeiric and shelf seas and lands are continued throughout later Paleozoic time, except for the absence of the St. Lawrencic and Acadic geosynclines. A part of the Acadic area is then occupied by the Northumberlandic embayment. The black line through Ohio is the axis of the Cincinnati geanticline, and the one through Illinois the Kankakee axis. Also see Pl. 1.

do not have the simple syncline structure, but are made up of many synclinals as well as anticlinals.

The oldest of the geosynclines are: (1) the *Appalachic,* in the eastern part, trending northeast-southwest; (2) the *Cordilleric,* in the west, with a north-south axis; (3) the *Acadic,* in sympathetic relation with the Appalachic; and (4) the *Franklinic* in the Arctic regions, with a northeast-southwest trend. The northern half of the Appalachic geosyncline (= St. Lawrencic trough), and all of the Acadic, were converted into mountains in the middle of the Paleozoic era (Devonian period), while the Franklinic and the southern half of the Appalachic rose into mountains toward its close, leaving only the Cordilleric geosyncline to continue into the Mesozoic era.

In the Mesozoic era, there developed within the great Cordilleric geosyncline a long and narrow land, the Central Cordilleran geanticline (see p. 468). Then there came to lie to the east of this land the vast (5) *Rocky Mountain geosyncline,* and to the west of it the smaller (6) *Pacific geosyncline.* At the close of the Mesozoic, in turn, the larger of these two troughs was folded into the Rocky Mountains, and only a southern part of the smaller or Pacific trough continued as such into the next or Cenozoic era.

Borderlands (study Fig. 314). — Borderlands are situated outside or oceanward of the geosynclines, and are periodically raised into highlands, though they never appear to have been folded while the troughs on their inner sides were subsiding. They may have been faulted and tangentially sliced and thrusted toward the geosynclines while the troughs were subsiding, but this action seems to have taken place mostly during the times when the geosynclines were being folded into mountains. Because the borderlands are periodically raised, they are the regions from which most of the sediments have been derived and delivered into the geosynclines.

The borderlands formerly extended an unknown distance out into the oceans. From the quantity of sediments that they have furnished to the geosynclines, it is certain that they continued beyond the present strand-lines at least 200 to 300 miles, and some of them doubtless considerably further. The quantity and nature of the sediments derived from them indicate something of their extent and the times of their periodic elevation.

North America is margined on the east by the borderlands *Acadis, Appalachis* and *Antillis,* each one of which has its own geologic structure and history, although little is known of the history of Antillis. Along the west coast is the greatest of all the borderlands, *Cascadis,* which later on divides into *Californis* and *Charlottis.*

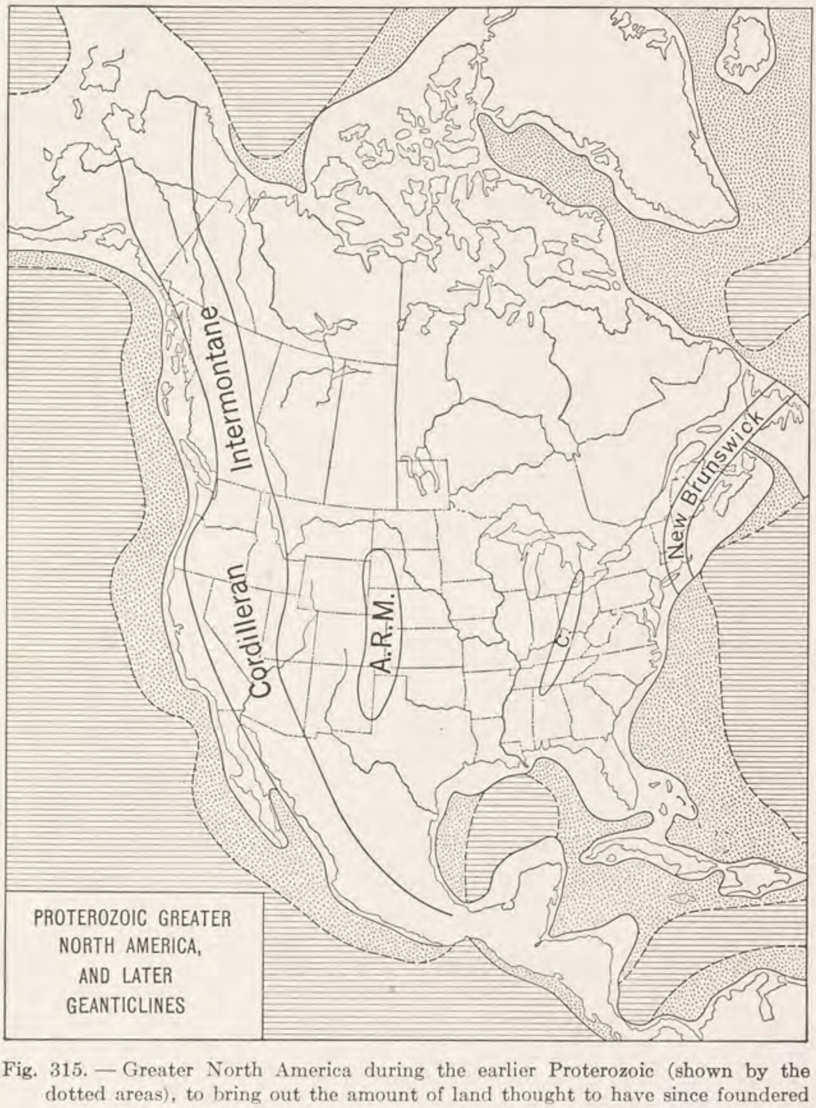

Fig. 315. — Greater North America during the earlier Proterozoic (shown by the dotted areas), to bring out the amount of land thought to have since foundered permanently into the oceanic basins, amounting to about 2,000,000 square miles. This map also shows the four geanticlines of North America. C, Cincinnati geanticline; A. R. M., Ancestral Rocky Mountains geanticline.

Mexico, or *Columbis*, appears to be an old nucleus, with a northeastern extension known as *Llanoris*. Finally, Arctic America is bordered by *Pearyis*, part of which is now elevated, along with the Franklinic geosyncline, into the folded United States Mountains.

Geanticlines (study Fig. 315). — Geanticlines are the broad upward bowings in the earth's crust, and differ at once from the common type of mountains in that their rocks were not folded during the time of elevation. The *Cincinnati geanticline* (often called the Cincinnati arch), the best known of these upward bowings, is a wide flexure in the earth's crust centering near the cities of Cincinnati and Nashville. Its width is something like 250 miles, and it was at times completely overlapped by the interior epeiric seas. The *New Brunswick geanticline* includes the granitic area of eastern Connecticut and Rhode Island and the White Mountains of New Hampshire, striking across central Maine into northern New Brunswick and southern Newfoundland. The *Ancestral Rocky Mountains geanticline* arose late in the Paleozoic era across eastern Colorado and New Mexico, western Kansas and Oklahoma, and northwestern Texas. This uplift was baselevelled early in the Mesozoic era, when the Rocky Mountain sea completely transgressed its roots. A part of it still remains in the present reëlevated Front Range (Long's and Pike's peaks) of Colorado.

Most extensive of all the geanticlines was the *Central Cordilleran*, extending from Alaska into Central America. To the east of it was the vast Rocky Mountain geosyncline, and to the west the smaller Pacific inland seas. This geanticline appeared early in the Mesozoic era, and exists to-day as the elevated Northern Interior, the Columbia and the much block-faulted Nevada-Sonoran plateaus.

CHAPTER XIX

EVOLUTION, THE CONSTANT CHANGE OF LIVING THINGS

Man lives and has his well being among plants and animals, but of the extraordinary abundance and variety of this life he generally has but the slightest conception. All of it, as well as all of inorganic nature, is well ordered and subject to unaltering natural laws, but this does not mean that all of Nature's parts are fixed and unchangeable, rather " nothing is constant but change." In other words, all Nature is in ceaseless change subject to natural laws.

Theory of Catastrophisms and Re-creations. — This changeableness of organic life has for a long time been perceived by thinking men, from the ancient Greeks onward, and various explanations of it have been offered. With the rise of the sciences, and more especially the accumulation of knowledge regarding the succession of ancient faunas in superposed strata, the theory of Catastrophism and Re-creations was developed. This theory, which was brought into general acceptance by the great Frenchman, Cuvier (1769–1832), held that in the past the entire world had undergone catastrophes which destroyed all the organisms. These were followed by long times of crustal stability, during which faunas more advanced than the previous ones were created. In Cuvier's time, however, the geologic sequence was poorly known, and his catastrophisms are now interpreted as the "breaks" in the geologic sequence, representing losses of record due to mountain making or other causes. Since then, the strata that fill in these breaks have in the main been discovered elsewhere, and these often have the transition animals unknown in Cuvier's time.

Theory of Organic Evolution. — In more modern times it was Galileo, Newton and Laplace who gave the thinking world a scientific theory as to the changes in the inorganic world; and Buffon, Lamarck, Darwin, Wallace and Spencer who foreshadowed the present theory of organic evolution. Charles Darwin is by general consent regarded as the father of the theory, since through his books, and chiefly the epoch-making *Origin of Species*, published in 1859, came the conviction that *life has been continuous, descending from previous life with change*, from the most primitive organism to the complex faunas and floras of to-day.

There is now no question about the truth of the theory of organic evolution as opposed to that of special creation. What is under discussion by the biologists is the detailed method by which Nature has brought about the manifold organic changes that we see. Scarcely any worker in the sciences of Botany, Zoölogy, or Paleontology now rejects the theory; in fact, all work in these studies is based on the concept of life having continuously descended from life since it began on the earth. The evolution theory is without doubt the grandest generalization of the nineteenth century, since it has not only transformed the method of study in Biology, Geology and the social sciences, but has given a new point of view to all science, art and even progressive religions.

Since, then, we are to accept the orderly development of life throughout the ages as the basis for our study of the organic side of Historical Geology, we may well sum up briefly the procedure of evolution as it is generally held by scientists to-day. The present theory is built around six basic concepts: (1) the prodigality of organic nature, living under (2) a constantly changing environment, brings about (3) individual variation, which through (4) the struggle for existence, leads to (5) the selection of the most fit (natural selection), and that which is selected by Nature as most fit for survival becomes more or less fixed through (6) heredity. In the struggle for survival, the possession of some slight variation may give one individual the advantage over the others, and the unfit, lacking this advantage, will in the long run be eliminated. The survivors, who have the advantageous variation, will pass it on to their offspring through heredity, so that in the course of time organisms better adapted to their environment will result.

Prodigality of Nature. — The prodigality of organic nature is beyond comprehension, and equally so is the wastage of individuals. More young are born each year than can possibly exist. Some individuals produce but a single offspring, while others cast upon the world many millions during the season of reproduction. Life's struggle is exceedingly harsh toward the young; they are mercilessly weeded out because of unfavorable habitations and starvation, snapped out of existence by a predaceous enemy, or made sick unto death by extremes of heat or cold, or by bacterial diseases. *Success in life is the rare exception.* In a struggle so severe, any advantage, however slight, may therefore be decisive in prolonging the life of the individual and stimulating the origin of new variations. All observant persons know that animals during their growth do not change into other species, and even though they alter their appear-

ance greatly from birth to maturity, these alterations are characteristic of the form observed and of no other. In other words, each species " breeds true " in its specific characters through heredity. A close comparison of this resemblance, however, shows that it is never absolutely exact, for each individual of every species has its peculiarities. No two organisms are exactly alike, and it is in these variations that the chance for evolution lies. Nature constantly eliminates the unfit, and through the survival of the fittest, the species are maintained, but with constant alteration. The whole course of evolution, therefore, centers in the processes of reproduction, and the favored individuals transmit their valuable qualities to their offspring, generation after generation.

Influence of Environment on Organisms. — So long as the environment of organisms remains unchanged, they undergo comparatively little modification. However, as the earth's shell has been periodically raised into mountain ranges and the oceans have as often flowed widely over the continents, it follows that the environment of plants and animals has undergone repeated and vast alterations. When mountains are thrown up simultaneously in many lands, great changes in the humidity and temperature of the atmosphere result, bringing on arid climates and even glacial ones. Such times are especially fraught with danger to the organic world. Evolution is then especially rapid, blotting out floras and faunas that have long dominated the earth, and forcing some of the small and insignificant stocks to take the lead and rise into new races which in their turn quickly attain mastery over their physical and organic environment.

This periodic appearance of new stocks of plants and animals, connected in the main with marked changes of the environment, is deeply impressive to the paleontologist, who is in an especially favorable position to observe it, seeing as he does the procession of life during the geologic ages. He therefore holds that it is the periodically changing physical conditions that are the greatest impelling force in organic evolution. On the other hand, the long intermediate times of equable and mild climate and nearly constant environment produce but slight specific alterations. Therefore, to the paleontologist evolution appears at times to proceed far more quickly, and as it were by leaps and bounds. These are the times of quickened adaptations to meet the great changes in the environment, while a slow or even stagnant evolution accompanies the long intermediate periods.

Succession of Life. — A great array of ancient forms of life is now known, and their appearance in geologic time has been determined.

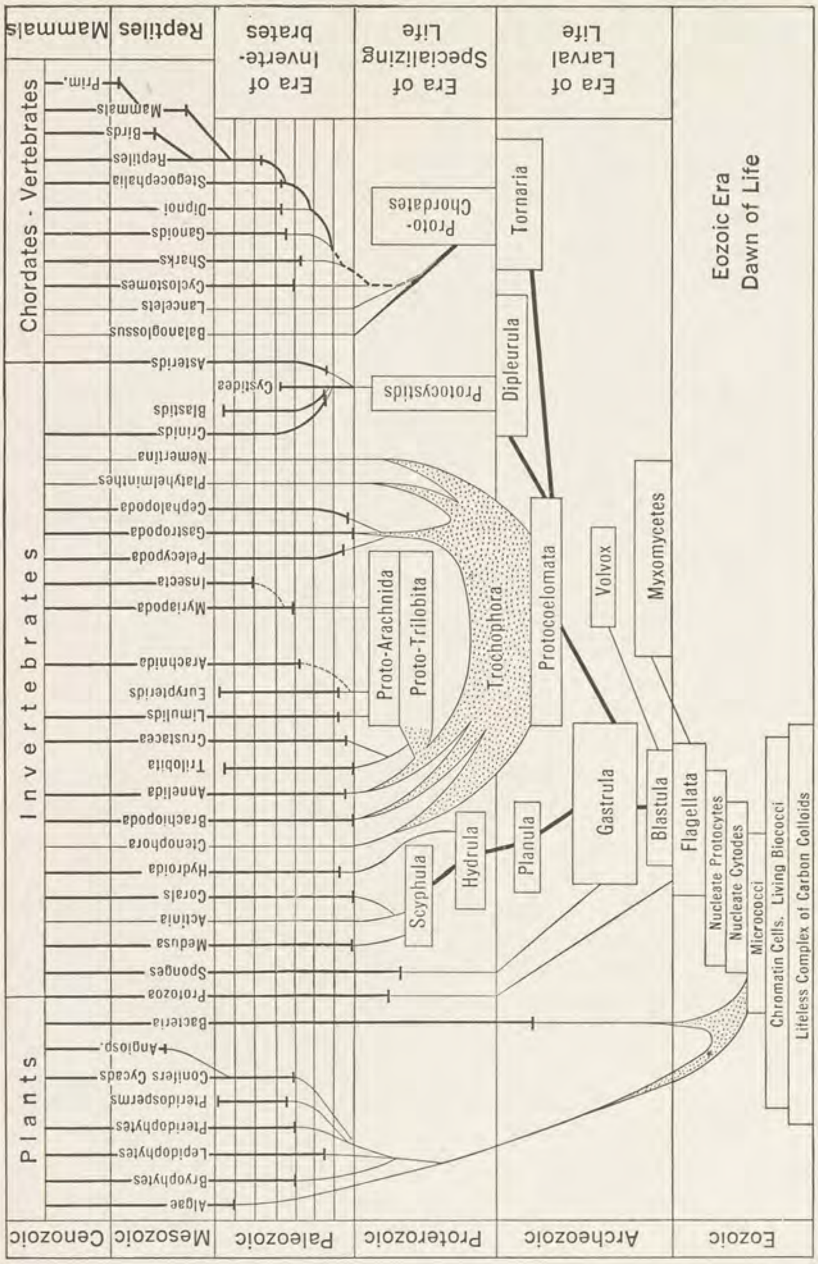

Fig. 316. — Diagram to show the time origins, phyletic interrelations, and geologic durations of plants and animals.

From this evidence we learn that Geology begins in obscurity, with an absence of all life. At the very beginning of the third great era, the Paleozoic, however, there is an abundance of marine forms, but nevertheless for a long time there is no evidence of land plants, and a land flora does not appear until still later times. The earliest animals all lived in the oceans, and out of them arose forms which could also breathe air and therefore could live on the land. Not a shred of evidence is at hand for the existence of animals with backbones (vertebrates) until long after the backboneless forms (invertebrates) originated, the first representatives of the higher type being the fishes. Later came the amphibia, out of which developed the primitive reptiles. Reptilian birds with teeth appeared after the reptiles, and these gave rise to the modern toothless birds. Reptilian mammals, on the other hand, originated earlier than the birds, and through a long and slow process of evolution finally gave rise to the placental mammals, the highest type of animals. Finally, the line of mammals leading to man appeared first in the lemurs (monkey-like forms), shortly afterward came the true monkeys, and more recently arose the anthropoid apes and the ape-man (study Fig. 316).

CHAPTER XX

FOSSILS, THE GEOLOGIST'S TIME MARKERS

All organisms, present or past, fall into one of two great divisions, the Plant Kingdom, or Plantæ, and the Animal Kingdom or Animalia. The former are the converters of inorganic matter into the organic structures upon which the latter are dependent for their existence. These kingdoms are each again divisible like the parts of a tree, the trunk representing the kingdom, and the branches the divisions of smaller and smaller import, down to the individual leaves (see Fig. 317). The individuals that are more or less alike in their trivial characters are grouped together as *species*, for example, the domestic cats. Then all the species that have characters in common are included in a *genus* (plural genera); such are the various kinds of cats (lion, tiger, puma, leopard, domestic cat), all of which belong to the genus *Felis*. The genera in turn are combined into *families*, these into *orders*, orders into *classes*, classes into *phyla*, and phyla into kingdoms.

For easier reference, the various divisions above cited may be grouped as in the following example:

Kingdom (Animalia);
  Phylum (Vertebrata, or vertebrate animals);
    Class (Mammalia, or mammals);
      Order (Carnivora, or carnivorous mammals);
        Family (Felidæ, the cats);
          Genus (*Felis*, a member of the cat family);
            Species (*Felis tigris*, the tiger);
              Individual.

Only about fourteen times in the history of life upon the earth have new animal phyla appeared. No new phylum has been evolved since the appearance of the fishes in the early Paleozoic, and no new classes since the mammals and the birds of the early Mesozoic. Hence all of the phyla trace their origin back to an early period in the history of the earth. Our knowledge of all this past life has come from a study of the organic remains preserved to us in the rocks, and it is the nature and significance of these life records, which are called fossils, that are to occupy our attention for the rest of this chapter.

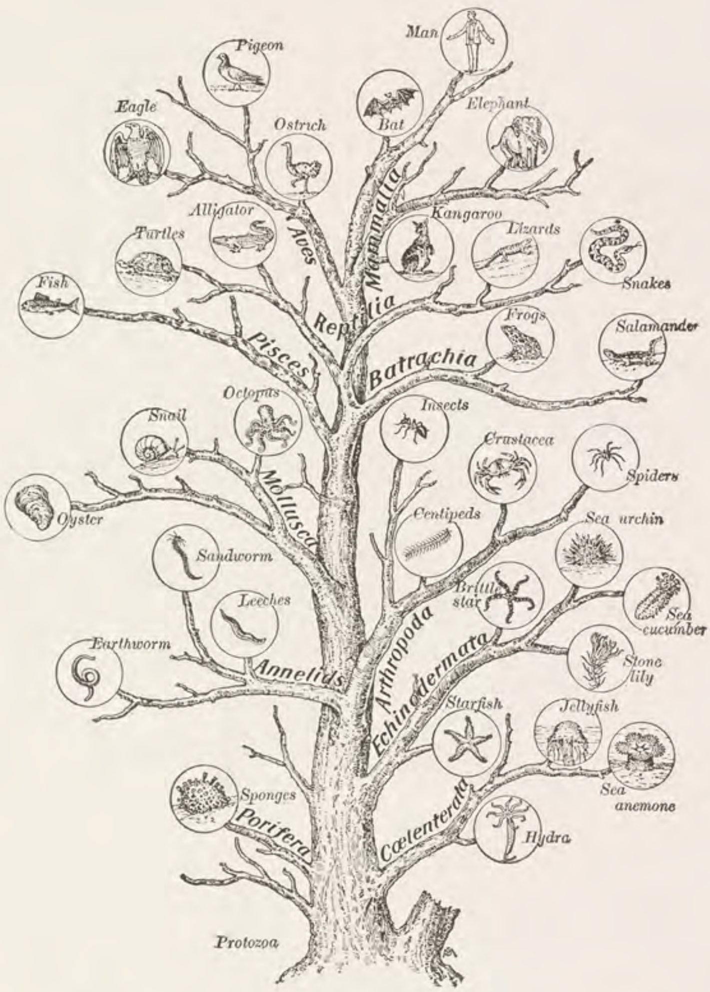

Fig. 317. — Genealogical tree of animal life, showing only the main branches (phyla). The diagram suggests the common origin of all animals in succession, with constant progressive change from the lowest (Protozoa) to more specialized types, and culminating in mammals and birds. The branching of a tree is usually taken to symbolize this interrelationship. From Gruenberg's *Elementary Biology* (Ginn and Company).

What Fossils Are. — Fossils are the remains of organisms that have lived in the geologic past, and the strata that contain them are the graveyards of the buried past, of the lost races connecting the past with the present. " The dust we tread upon was once alive " (Byron). The degree of perfection in fossils may vary all the way from the imprint of a leaf in shale or sandstone to an entire elephant, preserving not only the skeleton but all the soft parts and stomach as well, as in the extinct mammoth frozen in the Siberian tundras. Fossils are, however, in the great majority of cases, only parts of once living things.

How Fossils are Preserved. — Any dead organism of the lands or waters exposed to a temperature above the freezing point of water is, as a rule, at once attacked by the omnipresent microscopic fungi and bacteria, and by scavenging animals, and soon vanishes without leaving a trace of its former existence. In this process the oxygen of the atmosphere also assists. In other words, the individuals of entire floras and faunas vanish under the influence of other living things and of the atmosphere and hydrosphere; probably more than 99 per cent of all life has thus been removed. The only chance for an organism to be preserved after death as a fossil is for it to be covered quickly with sediment, and even then only a mold of the exterior form may remain. Complete destruction is the rule among all organisms having soft bodies devoid of hard skeletal parts, such as the jellyfishes, and even where there is a skeleton, either external, as shells, or internal, as the bones of vertebrates, preserval depends upon the chemical nature of these structures, upon the character of the sediments, and upon the chemical content of the waters in the rocks.

Due to these conditions, the chances for survival as fossils are naturally greatest among the life in the seas and oceans, since land life must be transported by fresh waters to some area of detrital accumulation. Fossils are to be especially looked for, therefore, in the evenly bedded strata of marine origin that are more or less calcareous (since the presence of lime helps to preserve the hard parts of animals), and least of all in the red shales and sandstones. In fresh-water deposits they are usually very scarce. Another type of sedimentary strata having the possibility of fossils consists of volcanic ashes, which at times of outburst are shot high into the atmosphere and then carried by the winds for shorter or longer distances over the lands and seas, burying all living things.

Kinds of Fossils. — Fossils occur in any one of seven different natural conditions, three of which relate to the substance left by

the organisms, three to their form and one to both. (1) The great majority of fossil specimens preserve more or less of the original hard or mineral substance of the individual plant or animal, and to this may have been added, during the process of mineralization, varying amounts of other mineral substance, forming *permineralized fossils*. (2) The original mineral matter may be exchanged for another and usually a dissimilar mineral, with the substitute preserving the original microscopic structure of the organisms; the woody parts of plants are often found in this condition and for study purposes are as good as the similar parts of living plants (see Fig. 318). (3) The woody parts of plants may be completely carbonized into coal, with

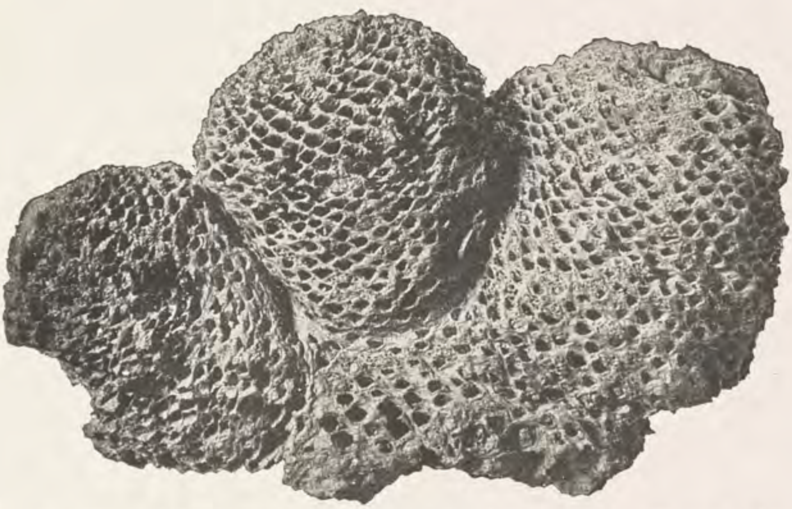

Fig. 318. — A fossil cycad, or plant distantly related to palms. The original wood is replaced by silica, yet the original microstructure is preserved.

the soft organic matter more or less entirely destroyed during the process.

The forms of organisms with the original substance absent may occur in the rocks as (4) *molds*, (5) *imprints*, or (6) *natural casts*. There is no marked difference between molds and imprints other than that the latter term is applied to impressions of thin substances, as leaves, etc. Natural casts are the counterparts of organisms made by filling the molds of fossils with foreign material. (7) When the replacing material is a crystallized mineral, *e.g.*, calcite, dolomite, pyrite, or more commonly silica in the form of chalcedony, the replacement is called a *pseudomorph*. (See Fig. 319.)

What Fossils Teach. — Fossils are not freaks of nature, as was once thought, nor are they merely chance relics of things once alive, but they are the very important geologic records from which has been unraveled much about the history of the earth. These records reveal (1) the course organic evolution has taken, along with the geographic distribution of plants and animals; (2) the sequence of geologic time or chronology; and (3) the nature of the environment of the fossils, whether they lived in marine or fresh waters or on the dry land, and something about the depth and temperature of the seas and the climates of the lands.

As the first-mentioned value is of most importance in pure Paleontology and general Biology, it need not be treated in detail in this book. The chronogenetic value of fossils is, however, of great import in Historical Geology. As all organic races, like individuals, have a span of life, and usually a short one geologically speaking,

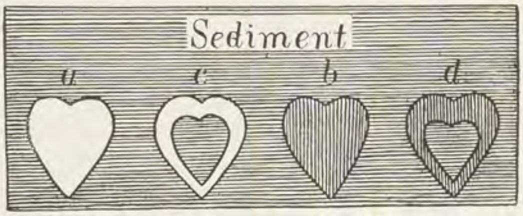

Fig. 319. — Diagram to illustrate molds and casts. The horizontal lines represent sediment, and the vertical ones the subsequent filling. *A*, the natural external mold of a bivalve with the shells removed by solvent waters. *C*, the same shell, but having the original cavity filled with sediment = natural internal mold. *B* and *D*, the molds filled by solvent waters with foreign materials = a cast and a pseudomorph.

and as species and genera are constantly changing, their degree of evolution is more or less indicative of the time of their existence. In other words, each stratum has fossils, or combinations of fossils, peculiar to itself, certain forms being so diagnostic as to be called "guide fossils"; these can be used accurately in correlating the strata of a given age from place to place or even from continent to continent. For example, an elephant tooth indicates late Cenozoic time; the imprint of a leaf of a flowering plant, post-Jurassic time; an oyster, post-Triassic time; and a trilobite, Paleozoic time.

Comparative Paleontology goes still further than this, and by knowing the trend of evolution in any stock, *i.e.*, having determined the relationship which fossils bear to each other, to those which preceded them, and to their successors, is able to find in the stages of these trends the fossil evidence of the sequence of the rocks which contain them.

In addition to dating the rocks in which they occur, fossils also afford testimony as to the environment in which they lived. Every species of the plant and animal world has a given home or environment known as a habitat, which may be dry land, rivers and lakes, or seas and oceans. Moreover, temperature varies between the poles and the equator, and therefore, organisms are cold, temperate, or tropical in their adaptations. All of these differences in habitat are reflected in the fossils. For example, we have learned from many years' study of the corals that they are always to be found in the oceans, never in the fresh waters, and that they make reefs only where the water is permanently warm. Hence the fossil coral reefs which we find in certain ancient rocks of Spitzbergen tell us that the sediments composing these rocks were laid down in warm seas. Again, the leaves of tropical bread-fruit trees, when found in the strata of Greenland, testify to a warm climate at that high latitude when the leaves were buried.

Organisms living on mud bottoms, though such are never common, will usually be different from those habituated to sand or lime bottoms, though the freely swimming or floating forms may at death fall on any kind of a substratum. For instance, most bivalves live buried in marine sands or muds, some only in the former, others only in the latter, and most brachiopods and all corals and bryozoans need some hard object or solid bottom to attach themselves to. In other words, organic nature everywhere has the impress of its environment, and through a study of the interactions of Nature in our own time we can learn how to unlock the riddles of the past.

CHAPTER XXI

THE GEOLOGIC TIME-TABLE AND THE AGE OF THE EARTH

Geologic history, like human history, falls into certain major divisions, and these in turn into minor ones. This long chronological sequence, which we know as the geologic column or time-table, has been pieced together by evidence from all lands, since, although the earth develops as a whole, the record is far from being everywhere equally complete. *It is the A, B, C of Historical Geology, and must be learned before further progress can be made.*

In Historical Geology the orderly sequence of time is determined (1) through the actual local order in the superposed sequence of stratified rocks, and in their overlap from place to place; (2) through the degree of evolution attained by the fossils contained in the strata; (3) through the unconformities or breaks in the sequence of rock formations; and (4) through the determined order in which the igneous rocks intersect or cut one another and the stratified formations.

Eras. — The longest division of time used in Geology is the era; the eras are the volumes in the book of geologic time. They are comparable in human history to the Christian era and, like it, characterized by a striking change in events. The era terms are taken from the Greek language and are based on the state of organic evolution present: Archeozoic (primitive life), Proterozoic (first [known] life), Paleozoic (ancient life), Mesozoic (medieval life), and Cenozoic (recent life). We are now living in the Psychozoic era, the Age of Reason.

The eras are bounded by great changes, both in the physical aspect of the earth and in its life. These are due to major times of earth shrinkage, causing the continents to stand high above the oceanic level. In many continents there was at these boundary times extensive mountain making, which brought about marked alterations in the environment, reacting strongly on the life of the time. Such times are called " critical periods " or revolutions; as an example may be cited the Appalachian Revolution between the Paleozoic and Mesozoic eras, or, coming nearer to our times, the Cascadian Revolution, out of which upheaval we passed into the Recent.

Periods. — A geologic era is composed of a group of periods, the chapters in the geologic volumes. As yet, however, it is not possible to give a short and clear definition of the physical and organic characteristics that distinguish periods from eras, and the following general statement must suffice. Each period embraces one or more invasions of the lands by the oceans and therefore one or more sedimentary cycles, the most extensive flooding occurring during the middle phase. On the other hand, the land intervals or breaks between each cycle of a given period are of much shorter duration and the organic changes less striking than are those between successive periods; in other words, the periods begin and close as a rule with the smallest inundations, have the greatest floods during their middle phase, and finally may close with a time of local or widespread and decided mountain making, known as a disturbance. They are often subdivided into *epochs*.

The names of the periods are generally taken from the regions in which the strata were first studied, even though the record may here be incomplete. Thus the term Silurian is taken from that part of England where the ancient Silures lived, and where the rock sequence is practically complete, while the Devonian period is named from Devonshire, where the sequence is so complicated by subsequent mountain making that its history had to be determined from the wonderful development in the Rhineland of Germany.

Formations. — The smallest geologic unit for mapping purposes is the *formation*, which may embrace a single more or less thick succession of like sediments, such as the Trenton limestone, or a succession or alternation of sediments that are unlike but have closely related faunas, such as the Hamilton formation. In short, any set of conformable strata that are without significant time breaks and are naturally grouped together because of certain stratigraphic or faunal reasons may be termed a formation.

Breaks. — Other time intervals which do not generally as yet appear in the geologic column, but which are nevertheless of great significance, are the erosion intervals, or breaks, the "lost intervals" in the succession of strata, when no local record was being made. Such times of lost record are known to be many, and the further growth of the column will come through the discovery of formation after formation along the lines of these breaks. Some of these records, however, and chiefly those between eras, are forever buried beneath younger formations or the waters of the oceans.

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA

Eras	Periods	Advances in life	Dominant life
Psychozoic	Recent	Era of mental dominance	Age of Man
Cascadian Revolution			
Cenozoic (Modern life)	Pleistocene or Glacial	(Periodic glaciation) Extinction of great mammals (Dawn of reason and of industry)	Age of Mammals and Flowering Plants
	Pliocene	Man-ape changing into man	
	Miocene	Culmination of mammals	
	Oligocene	Rise of anthropoids, higher mammals, and birds	
	Eocene	Vanishing of archaic mammals	
Laramide Revolution			
Mesozoic (Medieval life)	Cretaceous	Rise of archaic mammals, primates, and flowering plants Extinction of dinosaurs Extreme specialization of reptiles	Age of Reptiles
	Jurassic	Rise of toothed birds and flying dragons	Age of Reptiles and Medieval Plants
	Triassic	Rise of dinosaurs and reptilian mammals	

Geologic Chronology for North America (*continued*)

Eras	Periods	Advances in life	Dominant life
Appalachian Revolution			
Paleozoic (Ancient life)	Permian	Rise of reptiles and ammonites Last of trilobites and tetracorals (Periodic glaciation)	Age of Amphibians and Primitive Floras
	Pennsylvanian or Coal Measures	amphibians Dominance of coal floras and insects plant life	
	Mississippian	Rise of ancient sharks Maximum of crinids	
	Devonian	Rise of amphibians, marine fishes, and goniatites Climax Maximum of corals and brachiopods First land floras	Age of Fishes
	Silurian	Rise of lung-fishes and scorpions	Age of Fishes
	~~Champlainian or~~ Ordovician	Rise of land plants and fresh-water fishes Rise of corals	Age of Invertebrates
	~~Ozarkian and~~ Cambrian	Rise of cephalopods Dominance of trilobites First known marine faunas	

Geologic Chronology for North America (*continued*)

Eras	Major divisions		Physical and organic characteristics
	Grand Canyon — Killarney Revolution		
Proterozoic	Keweenawan Animikian-Whitewater Huronian Sudburian	Beltian of Rocky Mts.	Widespread glaciation Age of Primitive Invertebrates Great Iron Age Oldest glaciation (Canada)
	Laurentian Revolution and Laurentian granite intrusioı		
Archeozoic	Keewatin-Coutchiching	Grenville	Age of Larval Life
Azoic or time of no life. Transition between Cosmic time and oldest known geologic time			
Cosmic or Astronomic time			

The Age of the Earth

To measure the duration of geologic time became a definite scientific aspiration during the past century. Hutton in his studies of Scotch geology (1795) found "no vestige of a beginning — no prospect of an end." In 1860, John Phillips placed the age of the earth at 38,000,000 to 96,000,000 years, and geologists twenty years ago quite generally accepted 100,000,000 years as the probable age since the beginning of Archeozoic time. Then in 1903 came the epochal discovery of radium and the knowledge that this element breaks up at a definite rate that is measurable. Shortly thereafter the physicists told the geologists that they must multiply their figure at least ten times! Truly there is now an embarrassing richness of time.

The physicist's "radioactive clock" obtains figures of the order of 1,600,000,000 years since early in the Archeozoic, while the leading geologists nowadays readily admit on the basis of their hour glass that the sedimentary and saline records indicate a time of the order of 300,000,000 years. This estimate does not, however, take into consideration the uncountable breaks. Geology can, therefore, say

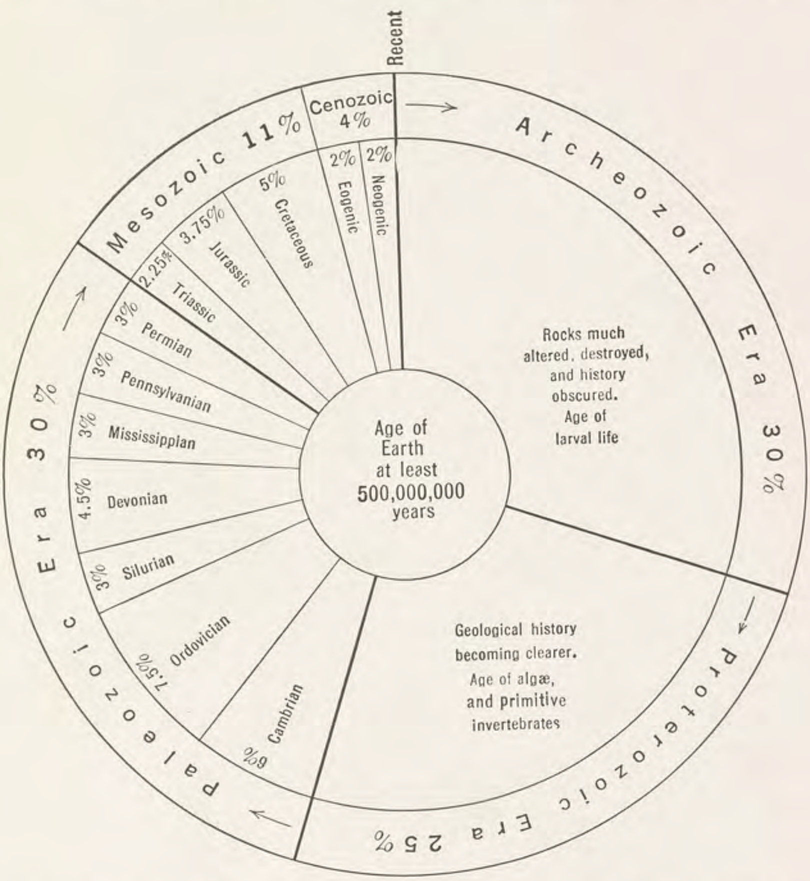

Fig. 320. — The geologic time-table arranged in the form of a clock dial, with the duration of each time division given as a percentage of the whole.

that the earth since the beginning of the Archeozoic is at least 500,000,000 years old. On this basis the geologic "time clock" has been adjusted in the figure above.

CHAPTER XXII

THE EARTH BEFORE GEOLOGIC TIME

Everyone knows that the earth is a definite mass of material, a planet controlled by the sun and making a yearly circuit around it in a definite elliptical orbit. Geologists always have before them in their deciphering of earth history the knowledge of an external shell of rock; the farther back they go into this history, the more obscure it becomes, but there still remains an earth differing from the present one mainly in having a different sort of atmosphere and in apparently being devoid of all life.

As material and forces are everlasting, however, there must be an earth history back of what the geologist discerns in the rocks, and in an attempt to ascertain these earlier stages he must seek the aid of the sciences of Astronomy, Physics and Chemistry. The starry heavens as seen by the astronomers through their wonderful instruments reveal this probable history, and it is this knowledge as interpreted by geologists, physicists and chemists that is now to be described in general terms.

Nebular Theory of Kant and Laplace. — Astronomy and Physics received a great impetus from Newton's principle of universal gravitation, given to the world in 1687, a principle that led to a sound conception of the evolution of the solar system. This Newtonian law was the basis of Immanuel Kant's nebular hypothesis, which that professor of mathematics and physical geography at Königsberg presented in 1755. Kant conceived that the universe must have been developed out of chaos and that space was filled with highly attenuated fundamental material, locally varied as to mass, density and attraction. In time this material segregated into the hot stars, of which the sun is one of the smaller representatives.

This conception of Kant was modified by the French astronomer Laplace, who in 1796 and again in 1824 proposed what has become known as the nebular theory of earth origin. Laplace thought that our ancestral sun, long before it gave birth to its family of four outer large planets and four inner smaller ones, was originally in a state of luminous vapor, extending even beyond the orbit of the vastly remote planet Neptune. This ancestral sun he pictured as a rotating

nebula of gas that was slowly contracting through loss of heat by radiation, and leaving behind one after another in the course of a long time nine rings of gas liberated from the equatorial region of its mass, which in turn condensed into the eight planets and the thousand or so much smaller bodies known as asteroids. However, astronomers now say that such tenuous gaseous rings, rotating as if they were solids, are unthinkable, and that no nebula is known closely resembling the one that supposedly gave rise to the solar system. They furthermore believe it to be impossible for such gaseous rings to draw together into planets and asteroids.

Planetesimal or Cold-earth Theory of Chamberlin and Moulton. — Nearly all the hypotheses as to the origin of the stars and sun derive

Fig. 321. — A spiral nebula in Pisces. Photograph by the Lick Observatory. This figure illustrates the solar nebula resulting from the close approach of the sun to another star. Out of the knots in the spiral arms, through the attraction to them of the innumerable planetoids, originated the planets and their satellites The sun spiral nebula was, however, much smaller than this one in Pisces.

them from an antecedent gaseous nebula. In regard to the origin of the earth, however, the most acceptable theory is the planetesimal theory of Chamberlin and Moulton of the University of Chicago. This theory holds that the sun, while in its early gaseous condition, either approached or was approached by another and probably a greater star, and that due to this mutual attraction tidal action was set up in the sun, partially disrupting it (see Figs. 321, 322). The material so ejected took on the form of vastly long spiral arms connected with the central body, but the mass in the arms was after all but a minimal part of the sun. This ejected material, according to

the authors of the theory, was mainly dust-like and they have called the particles *planetesimals*. Included in this cold dust-like material were many relatively large and probably hot masses, called knots, and these, attracting to themselves the planetesimals, built up the eight planets, their twenty-six moons, and the ring of asteroids, about a thousand in number, which lie between Jupiter and Mars. This stage in the evolution of the solar system endured through an immensely long time.

Fig. 322. — The great nebula in Orion, with irregular star condensing centers. In a gaseous and hot mass like this the sun is thought to have evolved. Photograph by Ritchey, Yerkes Observatory; two foot reflector, one hour exposure

Planetoidal or Hot-earth Theory of Barrell. — Chamberlin conceives the earth to have been built up as a solid body, not to have been fluid or viscous at any time later than the early nuclear stage. Barrell (1918), on the other hand, viewing the probable size of the planetesimals as equivalent to that of the asteroids (up to 485 miles in diameter), inclined to the idea of rapid infall of these larger bodies, which he calls *planetoids*, upon the earth nucleus. Accordingly, but

little time would be consumed during the growth stages of the earth, and the infall of the planetoids would lead to the formation of a hot earth with a fluid surface. This theory we will now develop further.

It can not be known, of course, whether during earth growth the center, or material of the original knot, tended toward a liquid or a solid state. The outer part of the earth, however, with a thickness of perhaps the outer quarter of its radius, comprising about one-half the volume of the sphere, seems to have passed into a truly molten condition.

After a long time, the rapid generation of heat by impact of the planetoids lessened, and the fluid sphere, seething with slow convection currents, began to cool. The heavy basic crystals were the first to form, and because of their high specific gravity they sank downward in the convective movement. The remaining higher magma was more siliceous, of lighter gravity, and in crystallization gave to the crust a greater proportion of feldspar and quartz. *The original crust of the earth was in consequence a granite.*

Azoic Time

With the formation of a crust, we may say that the Cosmic era in the earth's history had come to an end, and that geologic time begins. However, no one has yet consciously seen the smallest part of this original crust, nor has Geology discovered the oldest rocks that lie upon it. Therefore a time must be postulated to bridge the interval between the Cosmic events and the known Archeozoic era. This was done long ago by Dana, who defined an Azoic or lifeless era, the first part of which began with the granite crust, followed by the origination of the continents and oceanic basins, and of a heavy atmosphere.

Primordial Atmosphere. — Granting the initial fluid state of the earth, Barrell thinks there must have been at first a hot gaseous atmosphere consisting chiefly of water-vapor, and in lesser amount, carbon dioxide and carbon monoxide, chlorine and hydrochloric acid, with some nitrogen but no free oxygen. Geology now holds that the atmosphere and hydrosphere are essentially of volcanic origin, being the accumulated exhalations of active volcanoes and thermal springs. The gases come from deep within the earth, from heated and altering molten magmas. They are conceived of as dissolved in highly compressed magmas, and when the pressure is relieved, the evolving gases heat the magmas and finally escape into the atmosphere.

Gathering of the Ocean Waters. — When the crust began to cool and changed from a fluid to hard rock, crystallization went forward in various areas, convection was slowed, and finally the molten rock froze. Then rain, ever descending from the shield of perpetual cloud, but never heretofore attaining the crust or lithosphere, at last began to splash on the hot surface of the earth. A steaming earth's surface was of short duration, perhaps only a few thousand years. Then the surface began to assemble an ocean of acid water, probably universal over the lithosphere. Carbon dioxide became the dominant gas in the rare atmosphere, and water-vapor was present in subordinate amounts. Solar heat began to play the principal part in warming the earth through the now thin and broken cloud canopy. For the first time sunlight attained the surface of the lithosphere.

Volcanic activity was still very great and great volumes of gases were liberated, adding juvenile materials to the old or vadose atmosphere and hydrosphere. Ever since, new quantities of juvenile water and carbon dioxide have been added to the surface of the earth by the volcanoes. We may, therefore, say that the body of the earth has given forth its oceans.

Origin of Continents and Oceanic Basins. — According to Barrell, the fluid earth originally had a surface as level as that of the ocean. The problem of the origin of the ocean basins and of the continental platforms resolves itself into one of the origin of the density differences in the lithosphere and the maintenance of the heated and weak condition of the rocks beneath the stiff crust. It is thought that the disintegration of the radium-bearing minerals has acted as a permanent generator of heat in the rocks that contain them (see p. 264). Near the surface, this heat is lost through conduction, but that generated within the nucleus can not so escape but must slowly transform some of the solid rock into liquid form. In this way, reservoirs of molten rock arise that may melt themselves through to the surface. It is this deepest seated and heaviest magma that, by rising into the lighter subcrust, weights it and thus drags down into basin-form parts of the original granitic lithosphere. The forms and relations of the ocean basins suggest that in the earliest times, following the solidification of the earth, such dense molten matter from the depths of the earth broke into or through the outer crust on a gigantic scale, eruption following eruption until the wide-spread floods of rock had weighted down broad areas and caused them to subside into ocean basins. The waters then gathered naturally into the basins and the continents were left standing as elevated areas.

Regional crustal subsidence was especially characteristic of Azoic time, but the process did not cease then. In later chapters we shall see how the same process during the Mesozoic continued to break down great lands permanently into the ocean basins.

Evolution of the Atmosphere. — With the separation of the lands from the oceans, erosion began, carbon dioxide was abstracted from the atmosphere to make carbonates, and a further cause of atmospheric depletion was initiated. Thinner, rarer and colder grew the gaseous envelope, until an oscillating balance was established between the supplies of new gases from the uprising molten rocks and the loss involved in the weathering of their solid forms. Nitrogen was at first relatively small in quantity and oxygen not present in more than a trace. An evolution in atmospheric composition had still to go forward through the following Archeozoic era to transform it into a gaseous medium for the support of the higher land-living plants and animals.

Even early in the Azoic, following the gathering of the oceans and the emergence of the lands, the sun warmed the atmosphere and the earth. An environment suitable for the original and most primitive life had now arisen in the oceanic waters, since very low forms of marine plants, algæ and bacteria, are known in Archeozoic rocks.

In the primordial atmosphere, there must have been but a trace of free oxygen, since the latter was being consumed by the extensive lava flows of the time. The ocean waters were then almost fresh and the chlorine was combined with calcium and iron. Oxygen in notable amounts seems not to have been present until some time in the Proterozoic, since it is at this time that the first oxidized or red rocks appear (Animikian formation).

We see accordingly that the first plants must have been such that they could live without free oxygen, and they may have been like certain of the living bacteria (anaërobic). The green plants or seaweeds of the later oceans, however, made free oxygen in abundance, and with its existence animal life became possible.

CHAPTER XXIII

THE ARCHEOZOIC ERA

The greater part of Canada, or, rather, the Canadian Shield, of over 2,000,000 square miles in extent, exposes the oldest portion of the North American continent (see Fig. 323). Here lies the very complex record of event upon event, made during the two earliest eras of geologic history, which are considered to have lasted longer than all the remaining ones combined.

In deciphering this pre-Cambrian chronology the geologist has no fossils to depend upon, and the criteria used are of a physical nature, as follows: (1) similarity of rock character, (2) structural nature of the rocks, (3) superposition of the formations, (4) crustal movements, and (5) cycles of erosion. The study of the various pre-Cambrian formations makes it clear that their two most significant and distinctive features are: (1) the widespread crustal revolutions, characterized by vast upwellings of molten rocks; and (2) the profound depth to which erosion has planed, revealing over great areas deeper levels of the crust, which, while deeply buried, were subjected to regional metamorphism — levels whose original place was miles beneath the present surface.

Nature of Archeozoic Rocks. — The student of Archeozoic rocks is confronted with vast difficulties, since none of the formations are in their original condition. The water-laid sediments and the lavas and granites have been greatly altered through tremendous pressures of mountain-making forces, and bent and gnarled by intruded igneous masses, resulting in new rocks that are in a crystalline, gneissic or schistose condition. At many localities nothing remains as it was, all appears to be in hopeless confusion, and, therefore, the order of superposition of the formations, and the time value to be placed upon their contacts, are exceedingly difficult to establish. Because of this, the oldest known rocks are often called the *basement complex.*

The Archeozoic as a whole, however, is homogeneous in its heterogeneity; that is, it is alike in its extraordinary complexity.

The Lost Original Crust. — Geologists have as yet no evidence as to what took place in earliest Archeozoic time, nor have they seen

Fig. 323. — The surface distribution, in black, of the undifferentiated Archeozoic and Proterozoic formations. The gr at black area of Canada, together with Greenland, represents the Canadian Shield. After Bailey Willis, U. S. Geological Survey. Also see the geological map at the end of the book.

the original foundation upon which the Coutchiching, Keewatin and Grenville series rest. The evidence, therefore, is positive that the former foundation of the Canadian Shield, that is, the rocks older than those now resting upon the Laurentian granites, has been displaced or re-fused by the great upwellings of these, the most ancient of known granite rocks.

In the earliest but as yet undiscovered geologic history, the surface of the earth is thought to have had igneous rocks only, and these essentially granites. With the appearance of rains came the first sediments, the erosion products of granites and lavas, besides volcanic dust and solution materials like limestones dissolved out of the granites and lavas. The sediments must, therefore, have been sandstones and mudstones, and the limestones may at first have been precipitated chemically; later on, organisms took part in their deposition.

Archeozoic Formations. — The Keewatin and the Coutchiching are the oldest known formations of North America. The *Coutchiching formation* occurs typically in the Rainy Lake country of Canada north of Minnesota. It originally consisted mainly of carbonaceous shales, but these are now metamorphosed into mica-schists and dolomite, both probably of marine origin. The *Keewatin*, best known in the Lake of the Woods area of extreme western Ontario, consists of aqueous dark lava flows (usually basalts, now greenstones or schists), with some ash beds and black carbonaceous and sandy mudstones, now changed to schists. Like the succeeding Grenville, it has a wide distribution, but the outcrops are generally small and much localized. It represents one of the great outpourings of basalt in geologic time.

In the Province of Ontario north of the lake of the same name and east of Lake Huron, occurs a vast succession of essentially calcareous strata, the thick *Grenville series*, apparently the deposits of a transgressing shallow warm-water sea. They are now known to cover most of Labrador, Quebec, Ontario, the Thousand Islands, the Adirondacks and southern Baffin Land. In Ontario they reach a thickness of over 94,000 feet (nearly 18 miles), of which about 50,000 feet is limestone. The limestone phase is, however, practically limited to southern Ontario, the Adirondacks and Quebec.

Grenville rocks usually extend over the ground as long bands between areas of gneissic granites, since they commonly form steeply dipping synclinal structures between the bathyliths of Laurentian gneiss (see p. 495). These band-like structures are due to the strata having been domed by the rising bathyliths, which are now so deeply

eroded across as to expose only their roots and the deeper parts of the Grenville rocks.

Serpentine is common in the Grenville marbles, and here are found the fossil-like structures known as *Eozoön*, described on a later page.

Because of the shallowness of the Grenville seas, and because their muds and sands came from the Hudson Bay region, it is evident that *a great part of the Canadian Shield was already present in Grenville time* as a positive or continental element. This shows how far back in geologic time the rocks of this shield originated, and that the nucleus of North America probably came into existence during the formation of the earth's original crust.

The attention of geologists has long been attracted to the great quantity of graphite in the Archeozoic strata, chiefly in the quartzite-schists. Sir William Dawson long ago said that there was more graphite disseminated in the Grenville series than there is carbonaceous matter in the entire Carboniferous (coal-bearing) system. This graphite is believed to have originated in the main from the residuum of primitive marine plants.

In the Grand Canyon of the Colorado, Archeozoic rocks known as the *Vishnu series* are exposed in the Granite Gorge for 40 miles. In southern Arizona they are known as the *Pinal schists*.

The chief rock formation of the Canadian Shield is the widely distributed *Laurentian gneiss and granite*. This is the consolidation of numberless bathyliths that have welled up as molten magma into the older Keewatin and Grenville series. So prevalent are these granites that they cover more than 90 per cent of the Lake Superior country, and for a long time were regarded as the original cooled surface, or crust of the earth, upon which the above-mentioned formations rest. It has now become clear, however, that these granites are not older than the formations they seem to underlie, but that they are really younger, for they have upwelled from unknown depths of the earth, have broken up the older rocks, and shattered and invaded the formations above them. In other words, these basement granites are intrusives and therefore younger in age than the Keewatin and Grenville series which rest upon them.

Laurentian Revolution and Ep-Archeozoic Interval. — These granite cores, upwelling from below into the Keewatin and Grenville rocks, uplifted them into the Laurentian mountains, the oldest ones of the North American continent. In the southern area of the Canadian Shield they are thought to have been made up of individual elongate oval masses up to 50 miles long, and to have trended northeast. It is also probable that at no single time had they the

height and grandeur of modern mountains, but that after repeated vertical uplifts previous to Huronian time their total uplift and depth of peneplanation (erosion) were as great as those of most other mountain systems.

Then followed a long time of erosion, the Ep-Archeozoic Interval, reducing the highlands to a peneplain. This erosion interval is the

Fig. 324. — Laurentian peneplain as seen from Lake Michikamau, Labrador. Photograph by A. P. Low. Yale University Press.

most significant break in all North American geology, and the Canadian Shield the most remarkable of all known peneplains (see Fig. 324).

Evidence of Life in the Archeozoic

The direct evidence that life existed in Archeozoic time is exceedingly scanty, and yet it indicates positively that at least microscopic blue-green plants or algæ related to modern forms were living in the era (see Fig. 325).

Long ago Sir William Dawson described from the Grenville limestones *Eozoön canadense*, which means " dawn animal of Canada." These masses consist of irregularly alternating thin calcite bands and dark green layers, usually of serpentine, and result from metamorphism of the lime deposits. They are now regarded as probably of organic origin and are thought to be calcareous depositions, made by marine plants (algæ), and not by animals as the name indicates.

The usual absence of fossils in the Archeozoic does not disprove the theory that life began in soft-bodied microcosms; rather is it indirect evidence confirming the theory. Primordial life, to judge

on the basis of the growth stages of things alive now, was too perishable and minute to be preserved as fossils.

Fig. 325. — Blue-green alga related to modern forms. From an Archeozoic pebble in the Ogishke conglomerate, Minnesota. Photograph, × 190, by J. W. Gruner.

Indirect evidence in favor of the view that life abounded in the Archeozoic is seen in the wide-spread and vast amount of graphite in these sediments, which is largely if not wholly the metamorphosed carbon once in organic bodies.

CHAPTER XXIV

THE IRON-MAKING PROTEROZOIC ERA

The Proterozoic era represents a long time, seemingly 25 per cent of all geologic history. In the Rocky Mountains area at least 37,000 feet of sediments were laid down, and in the Lake Superior region upward of 53,000 feet of strata, and 22,000 feet of volcanics.

North America in Proterozoic Time. — From the geographic position of the earliest Paleozoic seas upon the continent of North America (see Fig. 314), and those of the late Proterozoic as well, it is plain that this land mass was not only outlined in much of its present form during the early Proterozoic, but that it was even larger than it is now. How much larger is not known, but seemingly it was then and for a long time subsequently widely connected by dry land with Greenland and eastward across the sea with Scandinavia. Accordingly about 2,000,000 square miles of greater North America has broken down into the oceanic basins in post-Proterozoic time (see Fig. 315).

The borderland Appalachis in the east and that of Cascadis in the west also came into existence during the Proterozoic (see Fig. 314). At the close of this era the Killarney mountains arose, dividing the interior of North America into a northern (Canadian Shield) and a southern (United States and Mexico) plain. In Arizona the Grand Canyon mountains were elevated. Toward the close of the Cambrian these mountains had in the main been reduced almost to sea-level, so that during the remainder of geologic time, nearly the whole of the interior of the continent was one vast plain.

Proterozoic Formations. — Upon the Laurentian peneplain from Lake Huron north to beyond Sudbury, Ontario, there rests the *Sudburian series* of essentially coarse marine deposits, as a rule arkosic conglomerates and quartz sandstones, with from 2 to 13 per cent of shales. Carbonaceous material, however, is completely absent in this series, which is often a cleanly washed sand of fairly equal grain, coming apparently from the north and transported by long rivers to a wide delta. The older arkoses were made either under a hot dry or a cool moist climate.

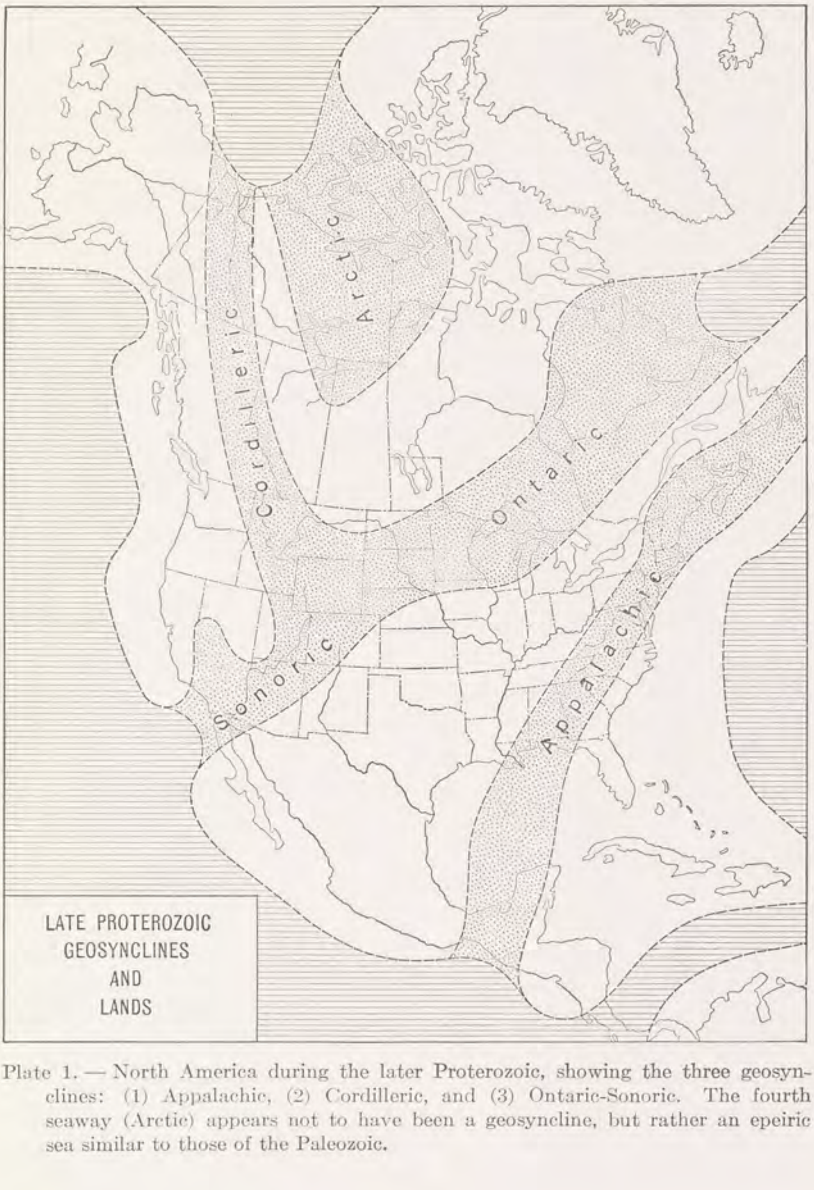

Plate 1. — North America during the later Proterozoic, showing the three geosynclines: (1) Appalachic, (2) Cordilleric, and (3) Ontaric-Sonoric. The fourth seaway (Arctic) appears not to have been a geosyncline, but rather an epeiric sea similar to those of the Paleozoic.

Where the Sudburian is not intruded by the later eruptives, it is but little altered, so that the original bedding, cross-bedding, and even the ripple-marks may still be seen on weathered outcrops. In fact, as the Sudburian strata are so very ancient geologically, their modern appearance is the most surprising impression made on the observer. From this we conclude that the atmosphere must have resembled that of later times in composition; water did its work then as now, and the extremes of heat and cold seem to have been normal.

Nearly all of the Sudburian formations are intruded, deformed and metamorphosed by intrusive granites which have been named *Algoman*. These are so much like the earlier Laurentian ones that it is very difficult to distinguish the two.

After the intrusion of the Algoman granites and the making of the Algoman mountains, followed the deposition of the *Huronian series*, which is now separated into an earlier Bruce division and a later Cobalt one. The latter division has as its lowest formation a bowlder conglomerate known as the Cobalt tillite, which is the oldest known glacial deposit; it will be discussed later in the chapter. The whole Cobalt division measures probably more than 12,000 feet in the region north of Lake Huron.

The next younger rocks, the *Animikian* or Great Iron Series, have a wide distribution over the Canadian Shield, the seas, it is thought, having transgressed far and wide over the older strata. Most of the deposits are of marine origin, though some appear to be of a continental character. However, the Animikian formations are not now of universal distribution over the shield; on the contrary, the areas are widely isolated and appear in the main to be remnants preserved from erosion in the down-folded or gently down-warped basins in the older rocks.

The Animikian strata generally lie nearly horizontal and are very little metamorphosed, but in certain areas are folded into large pitching anticlines and synclines. In the Penokee area of Michigan the formations that remain after their long exposure to the erosive forces are still 14,000 feet thick, but elsewhere they are usually reduced to a maximum of about 6000 feet.

The very thick carbonaceous deposits of the Animikian clearly mark the effective beginning of oxygen in the atmosphere, and the red color of much of the later Keweenawan and some of the Animikian sediments may indicate an increase in free oxygen to the point where it became effective as an enormous stimulant to the spread and rapid evolution of the animal kingdom.

The Animikian series is rich in iron ores, and about 70 per cent of the iron mined in the United States is of this time.

Above the Animikian in the Lake Superior region comes the *Keweenawan series* of rocks, all of continental origin, and of quick accumulation. Geologists are agreed that there is a distinct break in the record between the Animikian and the Keweenawan series of formations. Moreover, the sediments of the former are of marine origin.

The Keweenawan is characterized by enormously thick deposits, both of sediments and lavas, the igneous activity becoming greater in its middle and upper portions. The sediments are largely derived from the Laurentian granites, but red jasper pebbles of the iron formations also occur. Ripple-marks are common, the sandstones are often feldspathic and might be called arkose, and the shales have mud-cracks, all of which are indicative of continental origin. Further, the prevailing color is red, like the Triassic of the Connecticut Valley, suggesting desert conditions and complete oxidation.

This closing period of the Proterozoic record is marked in the region of Lake Superior by a tremendous outpouring of volcanic materials upon the dry lands, probably not by volcanoes but rather through fissures. In subordinate amounts ash rocks and lapilli are found between the lava sheets, and there are interbedded conglomerates, sandstones, and shales in small amounts.

From the human and economic point of view, the advent of the Keweenawan lavas was one of the most important events in the pre-Cambrian history of the Canadian Shield, since most of the valuable ore deposits of the region are connected with the igneous activity of this age. At Thunder Bay the silver ores of Silver Islet and other mines were supplied by the Keweenawan diabase dikes and sills, Ontario in 1913 yielding over $36,000,000 worth of silver. The unrivalled mines of native copper in Michigan belong to the amygdaloids and conglomerates of Keweenaw Peninsula.

The best known and thickest sections of Proterozoic formations in western North America, the *Beltian series*, occur in western Montana, eastern Idaho, and British Columbia, north to at least 54 degrees north latitude. Upward of 37,000 feet of sediments, mainly sandstones and shales, are exposed in the combined sections. A striking feature of these Beltian formations is the small amount of igneous materials.

In the Grand Canyon, Arizona, occur the *Chuar* and *Unkar* formations with a thickness, remaining after an unknown amount of erosion, of nearly 12,000 feet, most of which is sandstone, there being

only 435 feet of limestone, and that near the base. The sediments are at first of marine origin, but quickly pass upward into continental deposits. These formations rest on the peneplained surface of the highly deformed Archeozoic (Vishnu) strata. (See Fig. 326.)

Fig. 326. — View east up Colorado River, near mouth of Bass Canyon, Arizona. On the left and above are horizontal Paleozoic strata resting on peneplained monoclinal beds of the Proterozoic (Unkar). The latter lie upon the tilted peneplain of the Archeozoic (out of view) in the Granite Gorge of the river. Photograph by L. F. Noble.

Grand Canyon-Killarney Revolution. — After the deposition of these Proterozoic sediments, the rocks of the Colorado plateau region were profoundly block-faulted, tilted eastward, and elevated into a monoclinal attitude, and the resulting mountains were presumably high and in aspect not unlike the present Great Basin ranges. This orogeny is known as the Grand Canyon Revolution, and has its counterpart in the Lake Superior country in the Killarney Revolution to be discussed below. All the western mountains were eroded to sea-level before the Paleozoic era began, for the horizontal Cambrian strata rest upon the peneplained older formations (see Fig. 326).

In the Lake Superior region, at the close of the Proterozoic the whole area from at least Sudbury, Ontario, into southern Wisconsin was folded and injected by granite bathyliths, making the Killarney mountains. These have long been known as the "Lost mountains of Wisconsin." In a northeast direction they are known to have

extended at least 1000 miles, from southwestern Minnesota (Sioux Falls) to beyond Lake Huron (see map, Pl. 2).

Fig. 327. — Eroded exposure of the Huronian tillite, near Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

Fig. 328. — Areas of early and late Proterozoic glaciations.

Pre-Cambrian Climates. — One of the most surprising of recent discoveries in Geology was the finding by Coleman of tillites (morainal deposits of glacial till or bowlder clay, hardened into stone, see p. 144, and Fig. 327) in the Huronian formations of Canada, and

the consequent establishing of the occurrence of a glacial climate thus early in the history of the earth. Over the wide Laurentian peneplain previously described, there is found in the country to the north of Lake Huron a basal conglomerate that often includes facetted and striated bowlders of various kinds of rocks. Over the tillites occur, locally, thick zones of banded (varved) slate and water-formed conglomerates and quartzites.

Undoubted and probable tillites of Proterozoic age are now known in many other lands: certainly in Norway, China, India and Australia, and probably in Africa. They are of different ages, some occurring at the close of the Proterozoic and others older. (See Fig. 328.)

The very thick limestone series of both the Archeozoic and Proterozoic suggest that at the time of their formation the climate was at least mild. Then, too, the many zones of algal concretions, some of which are actual reef-limestones, point also to warm waters. In the Proterozoic, the vast amount of iron deposited is additional confirmation of mild climates. We may, therefore, conclude that at this very early time in the history of the earth the geologic climates were in general mild and fairly uniform the world over, but that at somewhat irregular intervals cold climates developed that were geologically of short duration.

Life of the Proterozoic

It is not so long since it was thought that the Proterozoic strata were devoid of recognizable fossils, but during the past twenty-five years such have been described from various places. Representatives of the two most primitive animal phyla, the Protozoa (Radiolaria) and the sponges (four orders), have been found in Brittany, France, and near the top of the Grand Canyon series siliceous sponge spicules have been found in the Chuar limestones.

The most abundant fossils of the Proterozoic limestones, however, are the secretions of calcareous algæ commonly known as *Cryptozoön* (Fig. 329). These coral-like plant masses make entire beds that repeat themselves again and again through thousands of feet of limestone. Great quantities of these algæ are common in the iron strata of Hudson Bay, Minnesota and Michigan.

From the upper portion of the Proterozoic (Beltian series) of Montana have been described a number of worm tubes and trails, seemingly of segmented annelids, that were found 7700 feet beneath the top of the section (Fig. 330). They are among the youngest

fossils known in the Proterozoic, and even though they are only tubes and trails they seem to indicate the presence here of annelid worms, a class of marine invertebrates high in the line of organic evolution.

Fig. 329. — Proterozoic reef of calcareous algæ (*Collenia ? frequens*), Flathead County Montana. Photograph by Willis, U. S. Geol. Surv.

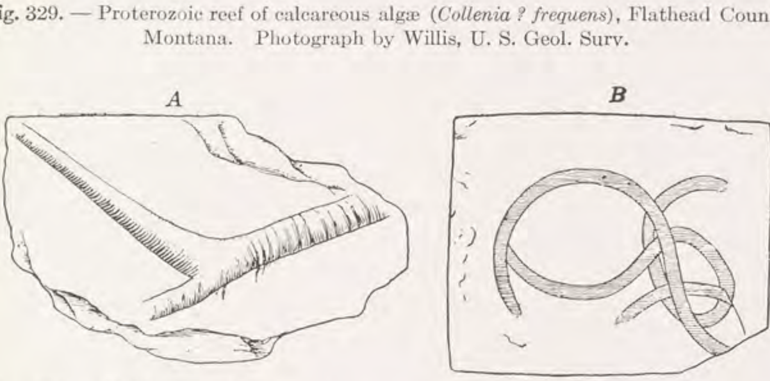

Fig. 330. — Evidence of Proterozoic worms. *A*, cast of large burrow (*Planolites corrugatus*). *B*, imprint of the actual annelid tube (*Helminthoidichnites meeki*). After Walcott.

This evidence shows that life was present in abundance early in the Proterozoic, and that it consisted mainly of marine algæ. In the later Proterozoic occur Protozoa (Radiolaria), Annelida, and various types of siliceous sponge spicules, and from the nature of the Cambrian faunas we must infer that trilobites were also present. This means that primitive forms of most of the invertebrate classes of organisms were in existence in Proterozoic time.

The Lipalian Interval

It is now the custom of geologists to speak of the unconformities also as breaks and intervals: breaks for the shorter times of lost record represented by the disconformities, and intervals for the greater ones seen in the angular unconformities.

Following the known events of the Proterozoic era, and before the introduction of Paleozoic strata with their abundance of fossils, there is an interval of very great significance. During the time of this Epi-Proterozoic interval, which has been called Lipalian time (from a word meaning gone or missing), the continents appear to have stood well above the general oceanic level, and the chief geologic work done was that of erosion. Where the Paleozoic strata rest on the Proterozoic, there is in most places a marked and usually an angular unconformity. In western Montana, Idaho and British Columbia, however, the Paleozoic rests without a marked unconformity on the Proterozoic or Beltian series. This condition means that here the lithosphere was not folded toward the close of the Proterozoic.

The marked and usually angular unconformity elsewhere beneath the Paleozoic means that mountain ranges had been elevated and subsequently worn away. Therefore, the land areas of Lipalian time were reduced to a low-lying plain, a peneplain, and it was over these flat lands that the Paleozoic seas spread with their fullness of life. How much time was consumed, no one knows, but it was long enough for much of the animal world to change its soft skin to one protected by a hard covering of carbonate of lime such as is seen in many of the invertebrates of the Cambrian.

CHAPTER XXV

CAMBRIAN TIME AND THE DOMINANCE OF TRILOBITES

We have so far studied in a most general way the more important geologic events of the earlier half of the earth's history. Now we begin to take up in more detail the better known chronology, beginning with the Paleozoic era. North America is wonderfully rich in a long succession of Paleozoic formations that abound in fossils, and this is especially true for the eastern half of the United States and Canada. No other continent is so rich in this history. In addition, the Paleozoic strata over vast areas west of the Appalachian Mountains lie almost as they were deposited, although of course much consolidated by time. The longest array of superposed strata is to be seen in the area east of the Mississippi River and in the Appalachians from northern Pennsylvania south to northern Alabama. Nowhere is there a complete record, but the gaps are not thought, as a rule, to represent very long intervals of time.

The Cambrian period of time or system of rocks takes its name from Cambria, the Roman name of northern Wales, where the deposits were first studied by Professor Sedgwick of Cambridge University, beginning in 1822. It is the first period in the Paleozoic era, and is generally separated from the older rocks by one of the most marked unconformities known, representing a very long erosion interval. It is also the first period in earth history with an abundance of life preserved as fossils.

Still another striking fact about the Cambrian period is that the Cordilleric and Appalachic geosynclines are now easily discerned seaways. Following the restricted geosynclinal seas of Lower Cambrian time came marked spreading of these waters across the continent as epeiric seas, beginning in the late Middle Cambrian and attaining greatest flooding in early Upper Cambrian times.

Finally should be pointed out the striking topographic fact that when the Lower Cambrian seas entered the Appalachic trough from the south, their waves broke to the east against a mountain tract as grand as the present Alps of Europe.

Cambrian Paleogeography (see Pls. 2 and 3). — In earliest Lower Cambrian time, the Pacific Ocean first invaded the land in the Great

Plate 2. — Lower Cambrian paleophysiography.

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 3 for Cambrian paleogeography.

The probable geography of Lower Cambrian time, without most of the drainage, which is wholly unknown. The seas are described on page 509, and the maps show the earliest and latest floods. The Ocoee mountains of Appalachis are described on page 509, and the Killarney mountains of Ontario on page 502. The other mountain areas of this time are more or less hypothetic.

The land was devoid of all vegetation, and the climate mild and more or less arid.

Basin area and gradually spread northward, forming throughout the Cordilleric geosyncline a sea which finally united with the Arctic Ocean. Shortly after the appearance of this western Cordilleric sea, a similar waterway appeared to the west of Acadis and Appalachis, finally extending as a narrow trough — the Appalachic geosyncline — from Alabama to southeastern Labrador. At its maximum the Lower Cambrian inundation did not submerge more than 18 per cent of the continent.

North America was then bordered by highlands that extended out into the oceans hundreds of miles farther than at present. On the west was the extensive land of Cascadis, and on the east were two land masses, the southern and greater one being Appalachis united with Antillis, which was more or less continuous with the northeastern one, known as Acadis. It was from these marginal highlands that came nearly all the sediments of the inland seas.

In northwestern Georgia, eastern Tennessee and western North Carolina, the very thick Ocoee and Chilhowee series, now demonstrated to be Lower Cambrian in age, represent the débris of mountains that then stood to the east of this area. These are the Ocoee mountains shown on the Cambrian map (Pl. 2).

Toward the close of the Lower Cambrian, the Appalachic geosyncline was drained of all of its marine waters, and a long time ensued before another cycle of deposition took place in this trough. What occurred at this time in the Cordilleric geosyncline is not yet clear, but there may have been continuous deposition here, and, if so, transitional faunas will be found, uniting the older ones with those of the Middle Cambrian.

During Middle and Upper Cambrian times most of North America appears to have been a lowland devoid of scenic beauty. Accordingly it was possible for the oceans to transgress the lands widely, as we shall see they did. If there were any highlands at all, they were in the bordering lands of Cascadis, Appalachis and Acadis. In the center of the great interior lowlands stood a low upland consisting of the roots of the Killarney mountains (see p. 502) that trended northeast and southwest across what is now the Lake Superior country.

The Cordilleric geosyncline continued its seaways throughout Middle and Upper Cambrian time. Late in the Middle Cambrian the Cordilleric marine waters began for the first time to spread across the continent toward the east, and throughout most of Upper Cambrian time the epeiric seas were of wide extent, especially in the area of the Mississippi basin. The Appalachic trough was also

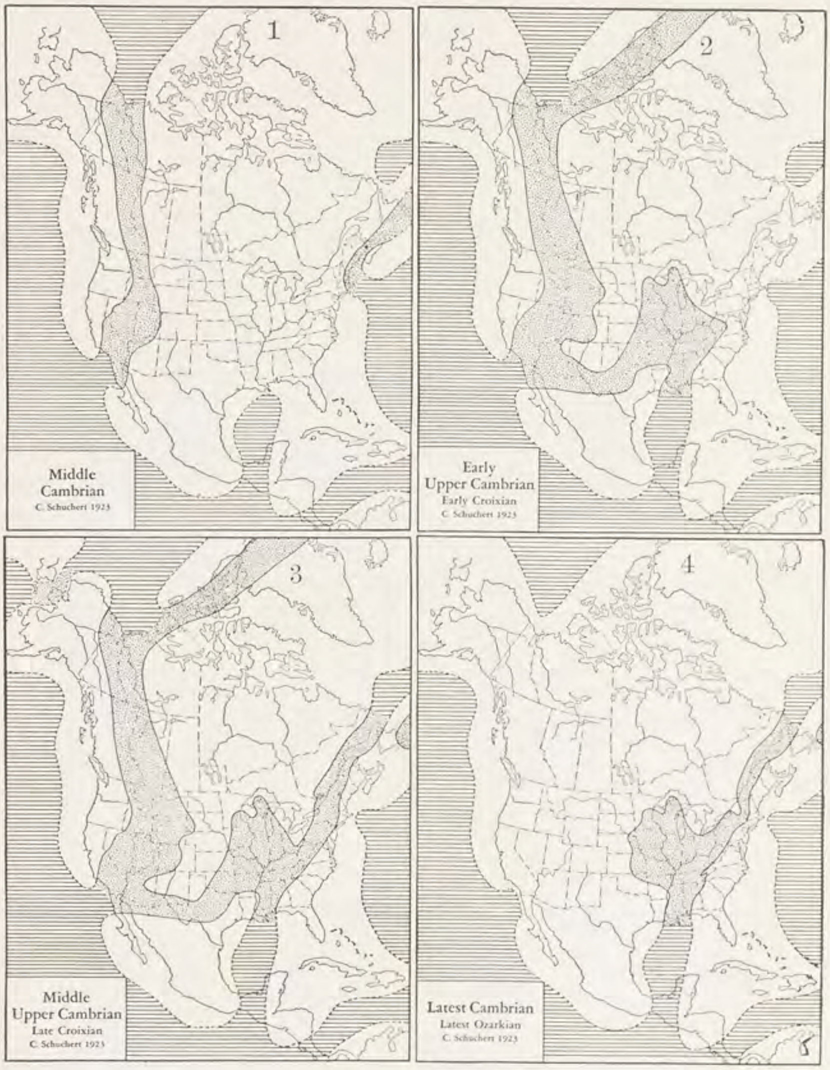

Plate 3. — Paleogeography of Cambrian time.

Epeiric seas dotted; oceans ruled. See Plate 2 for Lower Cambrian physiography. Note that the Cordilleric, Franklinic, and Appalachic geosynclines are in full development at this early time. The Acadic geosyncline had water in it only in Lower and Middle Cambrian time.

occupied by these waters of Pacific origin. When the flood was at its widest, it covered more than 30 per cent of North America (see Pl. 3, Map 3).

2. **Green Mountains Disturbance.** — At the close of the Cambrian the New Brunswick geanticline (see p. 467) was reëlevated, and in Vermont and Quebec the Cambrian limestones were locally broken up to furnish the material for the thick conglomerates at and near the base of the succeeding system of rocks, the Champlainian. This time of land elevation at the very close of the Cambrian is known as the Green Mountains Disturbance.

Life of the Cambrian

Of Cambrian animals, it is estimated that about 1200 kinds have been described from North America alone, fully 90 per cent of which are trilobites and brachiopods (to be described later), the trilobites making up about 60 per cent of the Cambrian faunas. This contrasts strangely with the scanty life known from the previous eras. It is all marine. Not the slightest evidence exists showing the presence of land plants in Cambrian time, though it is thought that the lowlands at least must have been clothed with feeble vegetation. There is also not a trace of land animals, either of fresh waters, or of dry lands. (See Pl. 4.)

The known life of the early Cambrian is primitive, as would be expected, but it is far from being the most primitive, since it ranges from simple sponges to complex forms of Crustacea, indicating that the ancestors of these many groups must have been present in pre-Cambrian time. The life was everywhere very much alike not only throughout America, but in Europe, Asia and Australia as well. It is, therefore, said to be cosmopolitan in character.

Beginning with the Middle Cambrian, however, there were clearly two life realms, the greater one of the Pacific (Albertan) and the lesser one of the North Atlantic (Acadian). The seas swarmed with life, the trilobites continuing their dominancy, followed by the brachiopods (see Pl. 4, Figs. 2–8). In the Upper Cambrian the gastropods (see Pl. 4, Figs. 9–14) began their ascendency, and the same was true of the cephalopods, though to a less striking degree. These last two groups will be described in the next chapter.

Trilobites (see Pls. 4, 7, 9, 12, 16; Text Fig. 331). — Trilobites were the first fossils to attract the attention of naturalists and have long been of popular interest. The great Swedish naturalist, Linnæus, first recognized their relationship to the Crustacea, animals such as shrimps, crabs and lobsters.

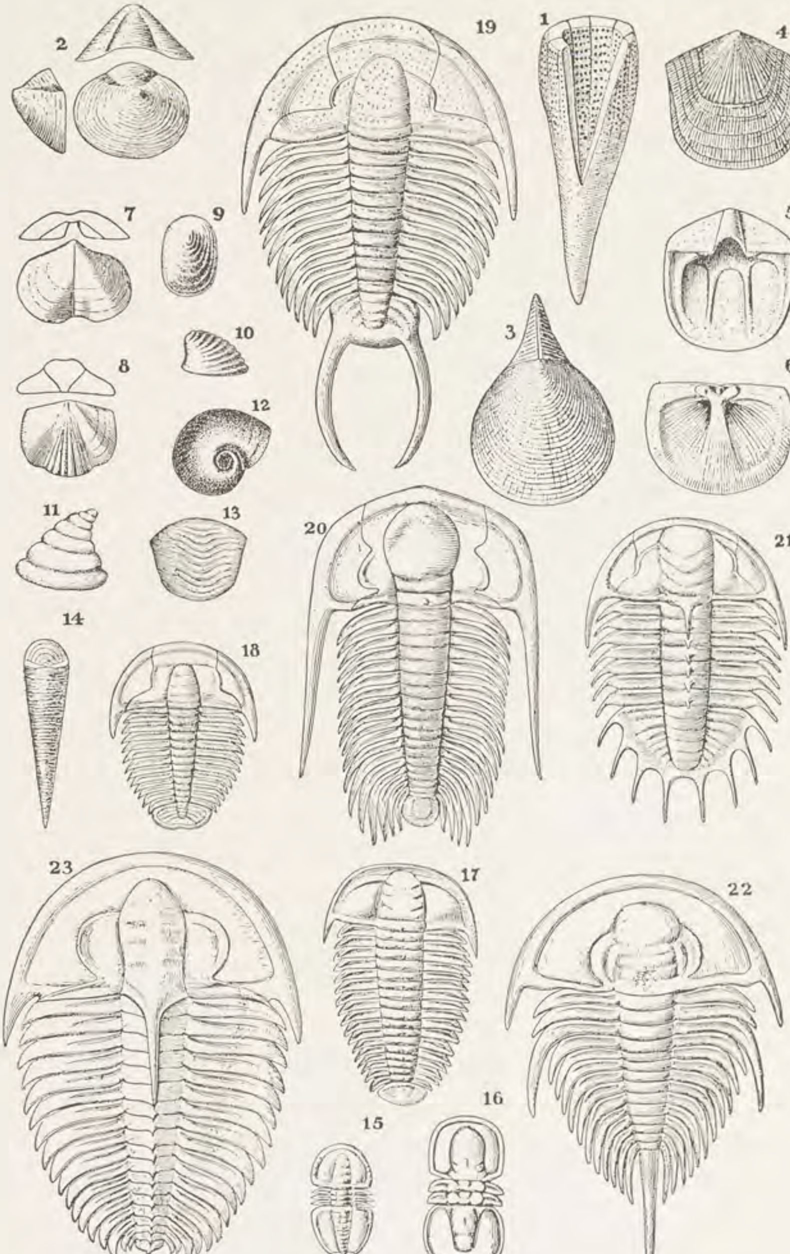

Plate 4. — Cambrian corals (Fig. 1), brachiopods (2–8), gastropods (9–14), and trilobites (15–23).

Fig. 1, *Archæocyathus rensselæricus;* 2, *Paterina bella;* 3, *Lingulepis acuminata;* 4–6, *Billingsella coloradoensis;* 7, 8, *Huenella texana;* 9–11, *Stenotheca rugosa;* 12, 13, *Owenella antiquata;* 14, *Hyolithes primordialis;* 15, *Eodiscus speciosus;* 16, *Agnostus montis;* 17, *Atops trilineatus;* 18, *Ptychoparia kingi;* 19, *Crepicephalus texanus;* 20, *Paradoxides harlani;* 21, *Dorypyge curticei;* 22, *Olenellus thompsoni;* 23, *Holmia bröggeri.*

The word trilobite means *three-lobe-like*, and has reference to the three longitudinal lobes (the central *axis* and lateral *pleura*) seen on the dorsal or upper side of most trilobites (see Fig. 331). They were sexed animals. Their bodies were made up of segments, many of which articulated upon one another; and these segments were gathered together into three divisions, as may be seen in any entire specimen of the upper shell or *carapace*, the part usually preserved. The under, or ventral side, with the limbs, had a very thin outer shell and was preserved only in exceptional conditions. The shell was made up of chitin (very much as in horn, hair, etc.).

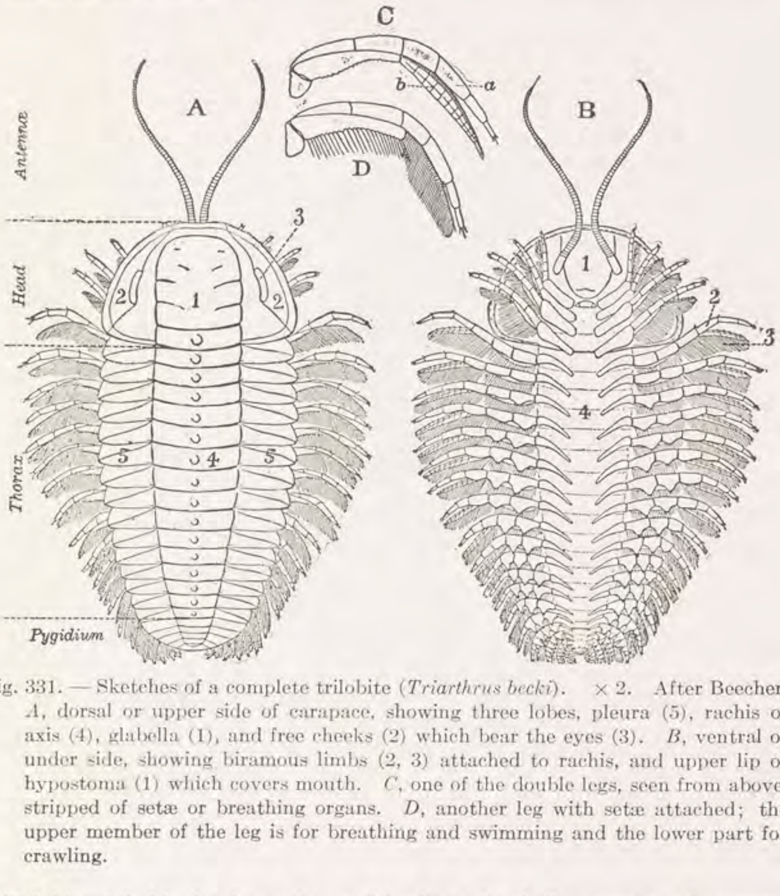

Fig. 331. — Sketches of a complete trilobite (*Triarthrus becki*). × 2. After Beecher. *A*, dorsal or upper side of carapace, showing three lobes, pleura (5), rachis or axis (4), glabella (1), and free cheeks (2) which bear the eyes (3). *B*, ventral or under side, showing biramous limbs (2, 3) attached to rachis, and upper lip or hypostoma (1) which covers mouth. *C*, one of the double legs, seen from above, stripped of setæ or breathing organs. *D*, another leg with setæ attached; the upper member of the leg is for breathing and swimming and the lower part for crawling.

Trilobites inhabited only marine, and in the main, shallow waters. In general they were rather sluggish animals, floating readily, but swimming probably in a jerking manner, and particularly backward, either with the ventral or dorsal side up. Over the sea bottoms they crawled slowly with the aid of numerous stout legs. The small species of highly spinous forms may have spent their lives floating and swimming in the plankton, while those with large eyes may have dwelt in the dark deeper parts of the seas, rising at night to the surface in search of food.

Most trilobites could roll their bodies up like the sow-bugs or pill-bugs of our cellars. This rolling up was for the protection of the more delicate parts of the ventral side, by presenting to the enemy the hard, thick carapace, an effectual armor against other trilobites but ineffective against the cephalopods and fishes.

As a rule, trilobites were carnivorous and as scavengers kept the sea bottoms cleaned of dead animals; some were omnivorous; others probably vegetarians; and a few were " mud eaters," the digestive tract assimilating the organic matter in the muds for bodily sustenance.

In size, the trilobites varied greatly at maturity, ranging in length up to 27.5 inches, but an average size was about 1.5 inches. Many species attained a length of from 3 to 4 and even 6 inches, but these were large individuals, and those above a foot in length were giants.

Trilobites were characteristic of the Paleozoic era, beginning in considerable variety in the Lower Cambrian, and dominating the seas of the Cambrian and the Champlainian. In the Silurian, though they were still common, the trilobites were nevertheless on the decline, and this ebbing of their vital force is

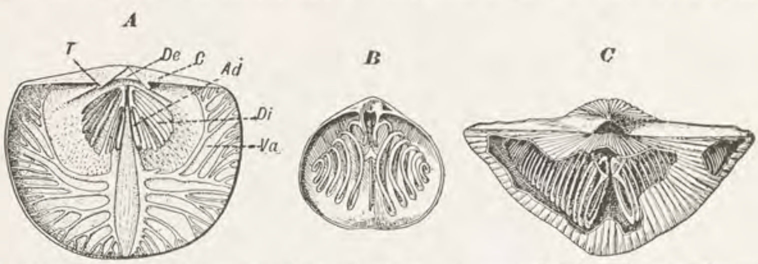

Fig. 332. — Internal characters of brachiopods. *A*, ventral valve of a strophomenid (*Rafinesquina expansa*). *B*, dorsal valve of a spire-bearer (*Nucleospira*), showing the skeleton that supports the arms. *C*, both valves with the dorsal shell broken to show the spiralia (*Spirifer striatus*). After Davidson. *Ad*, adductor scars; *C*, cardinal area, which also makes the hinge of the valves, and to which are attached the teeth (*T*); *De*, open delthyrium where the pedicle emerged; *Di*, diductor muscle scars; *Va*, vascular markings.

seemingly shown in many picturesque forms replete with protuberances, spines and exaggeration of parts. In the Devonian, the variety and number of the trilobites were greatly reduced, at a time when the ancient types of fishes, which undoubtedly fed on these crustaceans, began to be common in the seas. In the later Paleozoic, the trilobites vanished one by one, until a little before the close of the era none were left.

Brachiopods (see Pls. 4, 7, 9, 12, 16; Text Fig. 332) are marine animals, encased by two valves, usually of carbonate of lime. They differ from the lamellibranchs, which are also bivalves, in that the shells are situated on the ventral (belly) and dorsal (back) sides of the animals, and not on the right and left sides. The name Brachiopoda means *arm-footed*, and was given to the group because the early paleontologists thought they crawled around on their arms. They do not, however, move about, but are always fixed to one place, usually by a peduncle or stalk issuing from the ventral valve, except for a few days in the case of the newborn young. What were called arms are really breathing organs.

More than 200 kinds of living brachiopods are known, but they were particularly characteristic of Paleozoic time, when there were about 2500 known forms in North America. They appeared in some variety in the Lower Cambrian, but

their great development began in the Champlainian, and reached its culmination in the Devonian, with a renewed evolution of certain types in the early Mesozoic. They are of special importance as index fossils in the Paleozoic and Mesozoic.

Brachiopods are among the longest-lived animal stocks known, the genera *Lingula* and *Crania* having persisted through all the physical changes since the Cambrian.

CHAPTER XXVI

CHAMPLAINIAN TIME AND THE REIGN OF INVERTEBRATE ANIMALS

The Champlainian system of rocks (Ordovician of European geologists) lies above the Cambrian and beneath the Silurian, and the name is taken from Lake Champlain where it is well developed. The time of Champlainian endurance was considerably longer than that of any of the six other Paleozoic periods, occupying in fact about one quarter of this era.

Champlainian Floods (see Pls. 5 and 6). — Partly on the basis of the entombed fossils, but more particularly because of three distinct cycles of continental submergence, Champlainian time in North America is divisible into three epochs. During the period, the continent stood but little above sea-level, and it was only along its margins that there were uplands. For this reason it was easy for the rising oceans to spread widely over the land. The first flood was not of great extent, but the other two inundated the continent far more extensively than those of any other time.

These great seas spread the warm oceanic water widely over the continents, and, as is usual under such conditions, limestones were the dominant kinds of rock laid down. Champlainian time in general may well be spoken of as one essentially of limestone making. With the two greatest transgressions also came a profusion of marine invertebrates.

In no place has there been determined an unbroken deposition from the Cambrian into the Lower Champlainian. The submergences in the earliest division of the latter period were restricted to the Acadian and St. Lawrence areas, to the general Appalachian region, to the Mississippi Valley, and to the Cordilleran trough, with faunas peculiar to each section. At the close of this epoch, there was apparently emergence of the continent everywhere, and there is a marked change in sedimentation between its rocks and those of the succeeding Middle Champlainian. Moreover, the faunas of the two epochs are widely different. These changes show that the apparently insignificant break — the contact is everywhere a disconformable one — represents a loss of record long enough for the

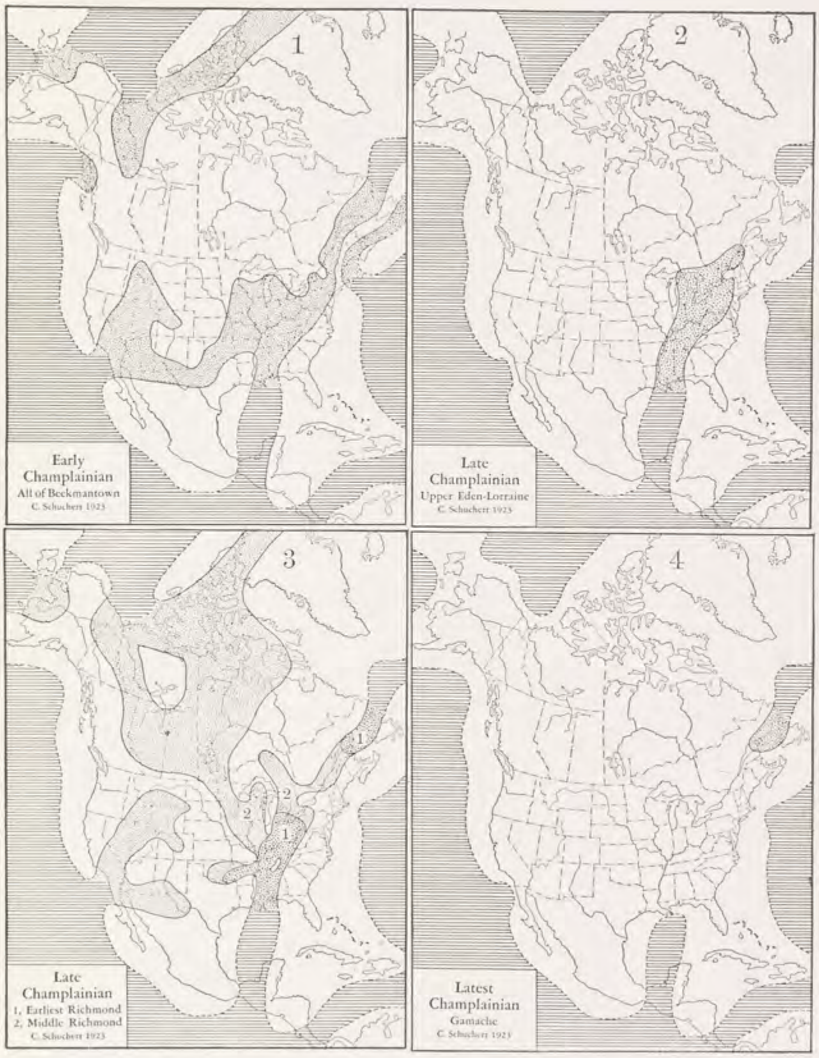

Plate 5. — Paleogeography of Champlainian time.

Epeiric seas dotted; oceans ruled. See Plate 6 for Middle Champlainian physiography.

Map 1 illustrates the first flood of this period; Plate 6 the second one; Map 3 shows the third flood, beginning in areas marked 1 and later becoming general; Map 4 brings out the widely emergent condition of North America toward the close of the Champlainian.

earlier faunas to have evolved into those so characteristic of the middle part of the period.

The Middle Champlainian was a long epoch and one with much change between land and sea. The seas were oscillatory and variable, with a final great inundation from the Arctic, the first of a series of Paleozoic floods from this ocean. The maximum submergence occurred in the latter half of the epoch (early Trenton time), when the seas covered about one half of the continent. Our knowledge of the Cordilleric sea of this time is not extensive, but there appears to have been a through waterway from the Great Basin country into the Arctic Ocean.

At about the time when the Arctic waters were spreading most widely across North America, a volcano stood somewhere in eastern Kentucky. This has been called Nelson's volcano, after the state geologist of Tennessee, who discovered the record of it in an ash bed covering an area of about 360,000 square miles and of a thickness ranging up to 7 feet.

After the great flood in early Trenton time, the waters began to retreat into the oceanic basins, first from the medial portions of the continent and finally from the northern ones. Some water appears, however, to have remained in the southern portion of the Central Interior sea, continuing here the marine record between Middle and Upper Champlainian times. The period of land dominance which separates the Middle and Upper Champlainian is called the *Mohawkian emergence.*

The Middle Champlainian sea had almost completely vanished from the continent when a new cycle of water movement spread from the Gulf of Mexico northeastward along the western side of Appalachis, northward into the Ottawa basin, and westward into Indiana. This brought back to the interior sea the previous southern faunas that had been changing elsewhere during the emergent interval into other forms. After nearly 500 feet of shales and thin-bedded limestones had been deposited, other floods from the Arctic Ocean and down the St. Lawrence arrived, spread their faunas far and wide over North America, and submerged more than 40 per cent of the continent (Richmond time).

In Middle and Upper Champlainian times the region from north of Cincinnati to beyond Nashville began to rise into a broad low arch, to the east of which was the Ohio basin, and to the west the Indiana basin. This arch, the Cincinnati axis or geanticline, did not, however, act as a completed separating ridge in the seas until after early Silurian time.

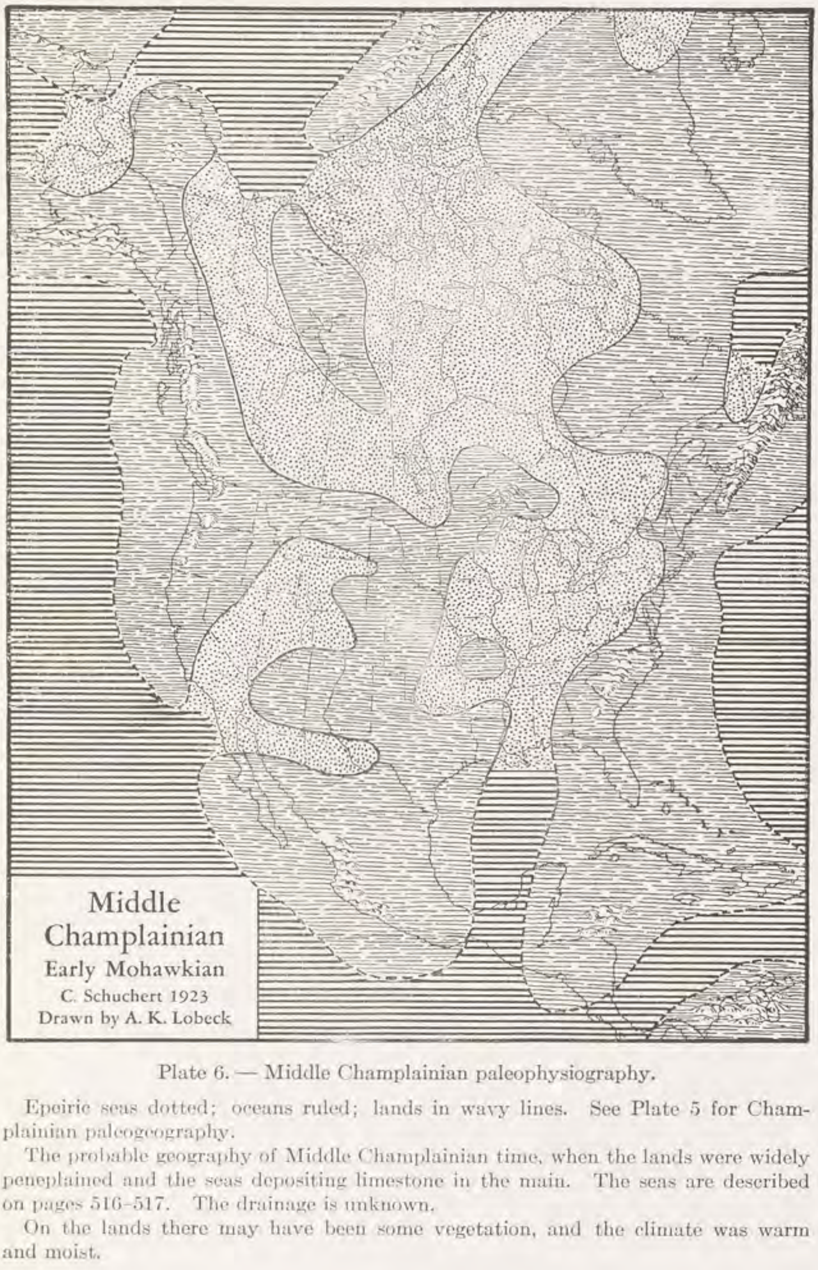

Plate 6. — Middle Champlainian paleophysiography.

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 5 for Champlainian paleogeography.

The probable geography of Middle Champlainian time, when the lands were widely peneplained and the seas depositing limestone in the main. The seas are described on pages 516–517. The drainage is unknown.

On the lands there may have been some vegetation, and the climate was warm and moist.

From this survey of the paleogeography of Middle and Upper Champlainian times, it is apparent that the seas were undergoing much change. This unrest in the hydrosphere was evidently due to movements within the bordering masses of the continent, not only depressing and elevating the land but affecting the general level of the strand-line as well. The greatest mass of sediments was laid down along the inner margins of Acadis and Appalachis, and here in the geosyncline, therefore, occurred the greatest depressions of the original land surfaces. In eastern Pennsylvania this maximum sinking was over 15,000 feet during Cambrian and Champlainian times. In the Great Basin area of the Cordilleric sea the sinking of the bottom took place mainly in the Cambrian, and here during the early Paleozoic the thickness of the strata is about 16,000 feet.

Taconic Disturbance. — In the New England-Acadian area (New Brunswick geanticline), there was wide-spread elevation beginning before Richmond time and seemingly renewed at the close of the period, known as the Taconic Disturbance. The deposits resulting from the wear and tear of this land are seen first in the wide-spread, red, thick deposits of the Upper Champlainian and later in the even thicker and more extended ones of the Silurian. Together these coarse deposits made up the Queenston delta of the medial Appalachian region.

Champlainian Climate. — The vast limestone and dolomite accumulations of Champlainian time throughout North America, which have an abundance and great variety of life even in the Mackenzie Valley and arctic Alaska, point, as has been said, to warm and equable waters. The same Middle Champlainian reef corals that are found in Tennessee and New York occur also in Baffin Land, the Mackenzie Valley and Alaska, though they are less abundant in the far north. We may, therefore, assume that the temperature of the lands and the seas in the northern hemisphere was nearly everywhere the same, and that it was warm temperate throughout.

Life of the Champlainian

The life of the early Champlainian varied in the different areas of deposition. Upward of 550 species are known, although if the strata were not so dominantly dolomitic, causing the destruction of the fossils, the total would probably be at least three times as great (see Pl. 7). The most characteristic animals of the St. Lawrence and Acadian seas were the *graptolites*, so called because of their resemblance in the fossil state to ancient writings on stone (see Fig. 333). They

were colonial marine forms, often of world-wide distribution, and therefore throughout the Champlainian and Silurian are of much importance in determining the age of strata from place to place. The Appalachian area during early Champlainian time is poor in fossils, owing to the alteration of the strata; here, however, in the dolomites are the lime-secreting algæ or seaweeds known as *Cryptozoön*, which often formed reefs, and in favored places are found thick-shelled gastropods and a variety of cephalopods, two groups to be described below.

During the Middle Champlainian, however, the life of the sea recorded itself by its fossils more completely than at any other time in the Paleozoic. The waters swarmed with a vast variety of invertebrate animals, and there are known from North America alone

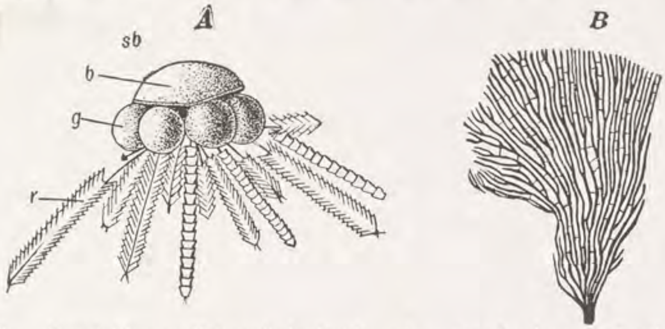

Fig. 333. — Graptolites or Paleozoic hydroids. *A*, restored colony of floating type (*Diplograptus pristis*). Somewhat enlarged. After Ruedemann. *b*, swimming bell; *g*, gonangia or brooding organs; *r*, a branch of many polyps in two ranges. *B*, dendroid type of anchored graptolites (*Dictyonema crassibasale*); the polyps are microscopic and like those in *A*. After Bassler.

more than 2600 species, chiefly of bryozoans (exceedingly small animals, remotely resembling corals), brachiopods (see Pl. 7, Figs. 3–19), gastropods (Pl. 7, Figs. 25–31), cephalopods and trilobites (Pl. 7, Figs. 32–40). The first true Paleozoic corals appear here and exhibit a tendency to form small reefs, while the bivalved molluscs and crinids (see p. 548) tend to be more common.

The Upper Champlainian faunas were at first very similar to those of the previous epoch, but the subsequent Arctic and Atlantic invasions introduced new types of animals which gradually changed into others prophetic of Silurian time. No new organic stocks arose, the faunal variations being rather those of detail within the groups already present.

Of the land plants of Champlainian time, very little has been recovered (Wales and Kentucky). Fragments of peculiar armored

Plate 7. — Champlainian sponges (Figs. 1, 2), brachiopods (3–19), lamellibranchs (20–24), gastropods (25–31), cephalopods (32–34), and trilobites (35–40).

Fig. 1, *Cyathospongia reticulata;* 2, *Zittelella typicalis;* 3, 4, *Platystrophia laticosta;* 5–7, *Hebertella sinuata;* 8–10, *Dalmanella testudinaria;* 11, *Leptæna rhomboidalis;* 12, 13, *Rafinesquina alternata;* 14, *Strophomena planumbona;* 15, 16, *Rhynchotrema capax;* 17, 18, *Triplecia extans;* 19, *Orthis tricenaria;* 20, *Ctenodonta cingulata;* 21, *Cyrtodonta huronensis;* 22, *Byssonychia radiata;* 23, *Pterinea demissa;* 24, *Colpomya constricta;* 25, *Protowarthia cancellata;* 26, *Cyrtolites ornatus;* 27, *Trochonema umbilicatum;* 28, *Eotomaria supracingulata;* 29, *Cyclonema humerosum;* 30, *Hormotoma gracilis;* 31, *Helicotoma planulatoides;* 32, *Orthoceras multicameratum;* 33, *Plectoceras* (?) *occidentale;* 34, *Schroederoceras eatoni;* 35, *Cryptolithus tesselatus;* 36, *Ampyx nasutus;* 37, 38, *Calymene meeki;* 39, *Ceraurus dentatus;* 40, *Isotelus iowensis.* (522)

fishes, the first of their race known, are abundant in Colorado, South Dakota and Wyoming, but are not found elsewhere. These first fishes are found in river deposits, a fact which we shall find to be of much significance in connection with their evolution.

Cephalopods (see Pls. 7, 12, 25; Text Fig. 347) represent the highest molluscan development. They include the chambered nautilids, which were abundant in the Paleozoic and still have a living representative in the pearly nautilus; the shelled ammonites, arising out of the nautilids by way of the goniatites (see Pl. 12), and developing into the most characteristic Mesozoic invertebrates; the shell-less belemnites, originating in the Mesozoic; and their descendants, the

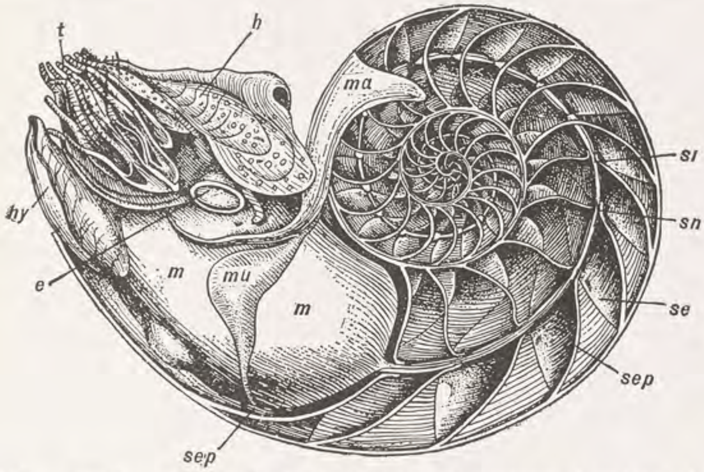

Fig. 334. — Pearly nautilus, with the shell cut through center to show internal chambers; the animal is fully expanded to show all of the external characters. × ½. After Hancock. *e*, large eye; *h*, hood or protective covering for the animal when retracted into the shell; *hy*, hyponome or funnel where water leaves mantle cavity; *m*, mantle, which encases animal and secretes shell (note prolongation into siphuncle); *ma*, dorsal prolongation of mantle; *mu*, muscle attaching animal to shell; *se*, chambers; *sep*, shell partitions or septa; *si*, siphon and siphuncle extending from animal through all the chambers to apex of shell; *t*, tentacles around mouth.

living octopus, cuttlefish and squid. All these forms are exclusively marine, and with their carnivorous habits and their alertness of motion, they ruled the seas of the Paleozoic until the coming of the marine fishes in the later Devonian.

Nautilids are the oldest and most primitive division of the cephalopods. They appeared with the Cambrian, were especially common in the Champlainian, but persisted throughout the Paleozoic and into the Mesozoic, waning with the latter part of that era. In the present ocean there are only four relic forms. The most primitive of the nautilids were straight, tapering cones, circular or oval in outline (*Orthoceras*, Pl. 7, Fig. 32), one of which reached a length of 15 feet (*Endoceras*). Some of their descendants began to coil, and finally became tightly wound, as in the living pearly nautilus (see Fig. 334). The shells were divided into chambers

by thin partitions called septa, and in life these chambers were filled with gas to make the shell more buoyant. The animals swam by forcibly ejecting inhaled water through a hyponome or funnel.

Gastropods (see Pls. 4, 7, 9, 16) are single-shelled molluscs such as the modern limpets, drills, periwinkles, whelks, snails, etc. They live under all conditions, in the seas, in the fresh waters, and on the dry lands, and are very varied the world over. The usual form of the shell is a spirally twisted cone with the apex upward, and because of this single shell they are called univalves, in contradistinction to the brachiopods and lamellibranchs, which have two shells and are therefore bivalves. Primitive forms of gastropods were present in the Lower Cambrian, but the twisted type appears more and more abundantly in the Champlainian. They are, however, not very valuable as time markers until the Mesozoic, when their shells are better preserved and they are far more varied. At present there are living over 20,000 species, a larger representation than at any time in the geologic past.

Lamellibranchs (see Pls. 7, 12, 16), so called because of their lamellar or plate-like gills, live between two shells, one on the right and one on the left side. They are, therefore, bivalves, but are known more popularly as mussels, clams, oysters, cockles and scallops. The shells are held open by an elastic ligament which acts like a spring, but are closed by muscles. The animals are nearly always free, and live chiefly in the oceans, but also in the fresh waters. The class was not well established until the Champlainian, but has persisted from then up to the present time. Their shells are often abundant in Paleozoic rocks, but are usually not well preserved until the Pennsylvanian. They are only occasionally of value as stratigraphic markers in the Paleozoic, but beginning with the Mesozoic, they are abundantly preserved and often serve as index fossils.

CHAPTER XXVII

SILURIAN TIME AND THE FIRST AIR-BREATHING ANIMALS

The term Silurian was proposed in 1835 by the great English geologist, Sir Roderick Impey Murchison, who was for a long time the director of the Geological Survey of Great Britain. The area where these rocks were first studied is the borderland between England and Wales, the home of the ancient Silures, a Celtic race who fought Cæsar's legions.

Silurian time is far shorter than the preceding Champlainian period. Almost everywhere in this country the strata of the two systems are easily separated by a more or less long "break" or interval, such as can be seen in New York State from Port Jervis northeast to Kingston and Becraft.

Seaways (see Pl. 8). — North America during the Silurian had about the same general topographic expression as in Champlainian time; that is, the greater interior basin stood but little above sea-level, while the highlands, as heretofore, were toward the margins of the continent. Twice was the interior low area transgressed by great floods, first during the early Silurian (Alexandrian epoch) and later during the middle part of the period (Niagaran epoch), when from 30 to 40 per cent of the continent was under water. These floods came from the Arctic and down the St. Lawrence, spreading south into the United States, while smaller seaways spread from the Gulf of Mexico northward. There was also a small seaway in the Acadic geosyncline that was especially marked by the life of the English seas. Of the Cordilleric seas little is known.

In the Appalachic trough the sedimentaries are coarse-grained throughout until near the close of the period, when much earthy limestone (cement rock) was deposited in very shallow seas, as is indicated by the decidedly sun-cracked strata. The coarse-grained rocks are the results of rapid erosion from the highlands of Appalachis and Acadis following the emergence of late Champlainian time. The thickest accumulations occur in east-central Pennsylvania, with valuable iron ores throughout the Appalachic geosyncline. The upper 2000 feet of Silurian rocks consist of shales gradually becoming more and more calcareous toward the top and bearing

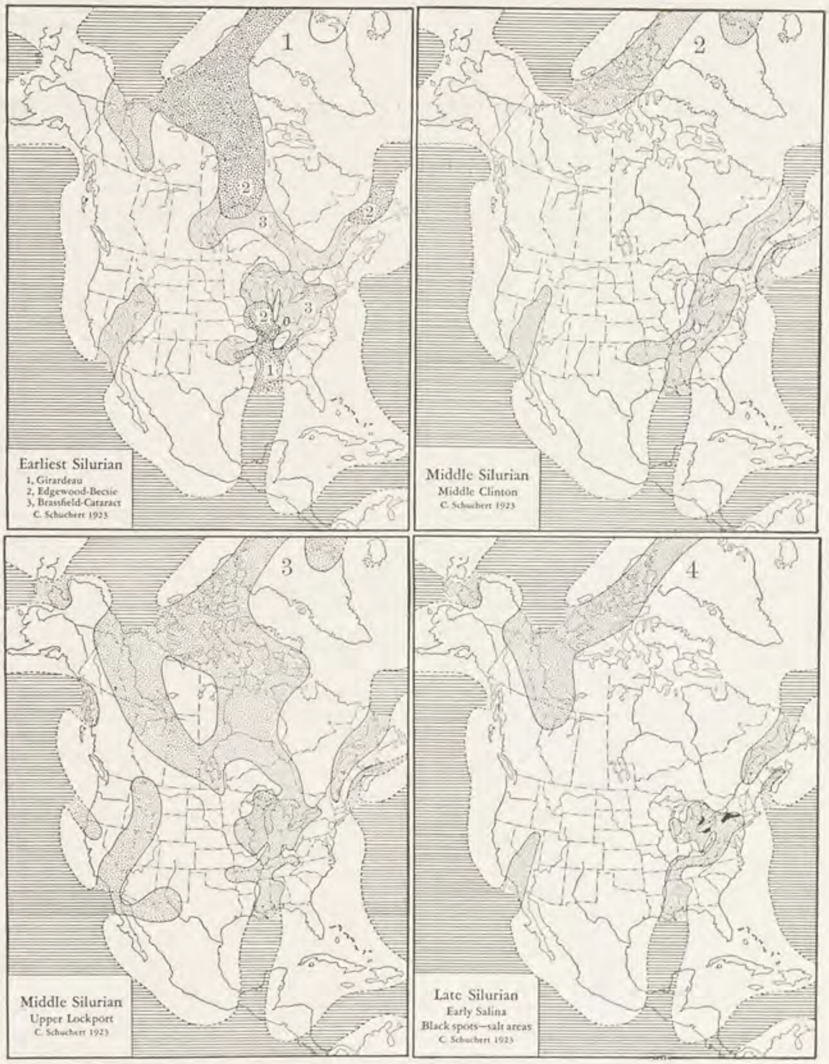

Plate 8. — Paleogeography of Silurian time.

Epeiric seas dotted; oceans ruled.

Map 1 shows three different stages in the flood of Alexandrian time. Maps 2 and 3 show the progression of the second flood, while Map 4 has the lingering seas at the close of the period, some of which were salt-making basins (the three black spots) during the arid conditions of this late Silurian time.

valuable deposits of rock-salt and gypsum in New York, Ohio and western Ontario.

Between Buffalo, New York, and the region about Niagara Falls may be studied a typical Silurian section, and one of the finest exposures in America for strata of this time. The gorge between the Falls and Lewiston has the lowest strata reposing on the Champlainian, while the younger deposits appear in sequence toward Buffalo. The diagram on page 528 illustrates the sequence of the beds and the picture shows them as they appear in the walls of the gorge of the Niagara River (Figs. 335 and 336).

In the interior part of the continent, the Silurian dolomites and limestones are of clear and warm waters, and most of them were deposited in Middle Silurian time. The strata were widely distributed in two epeiric seas, one being the smaller southern Central Interior sea and the other the far larger sea of the Arctic region. Nowhere are these deposits thick.

Volcanoes. — No mountains were made in North America during Silurian time. Active volcanoes, however, were common in southeastern Maine throughout the Middle Silurian, as indicated by thick Silurian deposits which consist almost wholly of ashes. At the same time other volcanoes throughout a great part of the Gaspé Peninsula in Quebec were pouring out vast volumes of lavas; at Black Cape in this region the lavas are several thousand feet thick and the earliest flows are interbedded with late Middle Silurian limestones.

Caledonian Mountains of Europe. — In Great Britain, toward the close of the Silurian, arose the majestic Caledonian ranges, extending from Ireland and Scotland into far northern Spitzbergen. This was one of the most important times in the geologic building of the British Isles, and the Caledonian ranges must have been grander and loftier than the Alps. In Norway and Sweden, the pre-Devonian strata, over an area 1100 miles long, have been overturned and pushed horizontally eastward some tens of miles.

Silurian Climate. — Since the Silurian seas abounded in varied life, as we shall see later, and since the deposits in the main were dolomites and limestones as far north as the Arctic regions, it is but natural to infer that these waters were warm. Additional confirmation is had in the almost universal distribution of the reef-making corals. Further, extensive salt-depositing seas existed in eastern North America between 40 and 45 degrees north latitude, during late Silurian times, indicating a warm and dry climate on the land. We may, therefore, conclude that the climate of Silurian time, in the

Fig. 335. — General view of New York side of Niagara River gorge. Clinton limestone at track level, the long slope is Rochester shale, and the vertical upper walls are Lockport dolomite, here about 25 feet thick; at the falls the Lockport is 80 feet thick, but its total thickness is 130 feet.

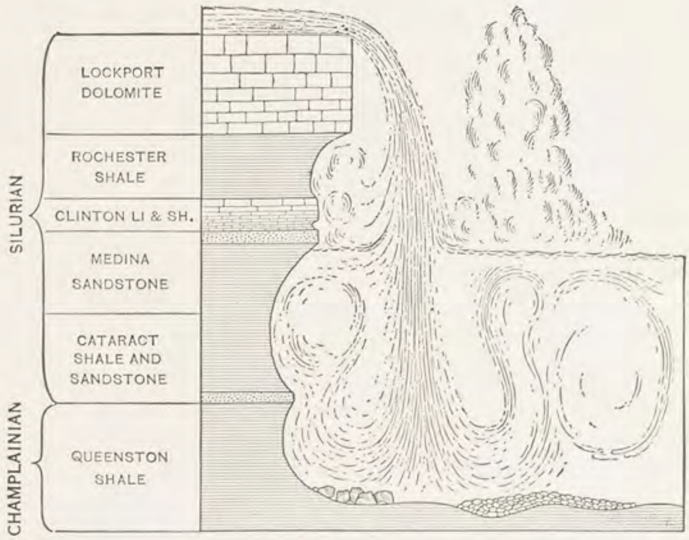

Fig. 336. — Sectional diagram through Horseshoe Falls, Niagara River, showing sequence of formations and depth of water below falls. Height of falls, 158 feet; depth of water, 150–200 feet. Modified from G. K. Gilbert.

United States at least, was temperate to warm. Tillites of Middle Silurian time are known, however, in Alaska.

Economic Products. — In the Middle Silurian Clinton formation of the Appalachic trough from New York to Alabama, there occur in many regions one or more beds, varying from a few inches to 10 and even 40 feet in thickness, of regularly stratified, argillaceous, red iron-ore or hematite (Fe_2O_3). They contain from 30 to 50 per cent of iron and were formerly mined throughout the Appalachian Mountains, but are now worked extensively only in the Birmingham region (Red Mountain) of Alabama. It is said that over 600,000,000 tons of these oölitic iron-ores are still available underground.

The Upper Silurian Salina deposits of central New York, southern Michigan and Ontario, are one of the very important sources of salt in the United States. The salt is obtained by deep mining of rock-salt, or by underground solution, the water being forced down through one driven hole and pumped out of another, and the brine evaporated.

Life of the Silurian

On the basis of their faunas the American Silurian deposits are geographically divisible into four provinces (1) Atlantic, (2) Southern, (3) Arctic and (4) Cordilleran. The best known of these, with the longest and least broken record, is the Southern province, embracing the Silurian deposits of the southern portion of the Central Interior sea and the Appalachic trough. The Arctic and Atlantic provinces, of Lower and Middle Silurian time, include much of the northern interior part of the continent south almost to the Ohio River, and have decided faunal connections with northern Europe. During the middle part of the period, however, when the inundation of the continent was greatest, the faunas of all the provinces took on a more cosmopolitan appearance and had the greatest number of species in common.

The invertebrates still dominated the seas (see Pl. 9). Upward of 2500 species have been described from the American Silurian, the common ones being mainly corals, crinids (see p. 548), bryozoans, brachiopods and trilobites. True graptolites were still common in the European seas, but in America they are not often found as fossils.

Of trilobites there were still many species, some of which were bizarre looking animals with spines on the head and tail (see Pl. 9, Figs. 18–21).

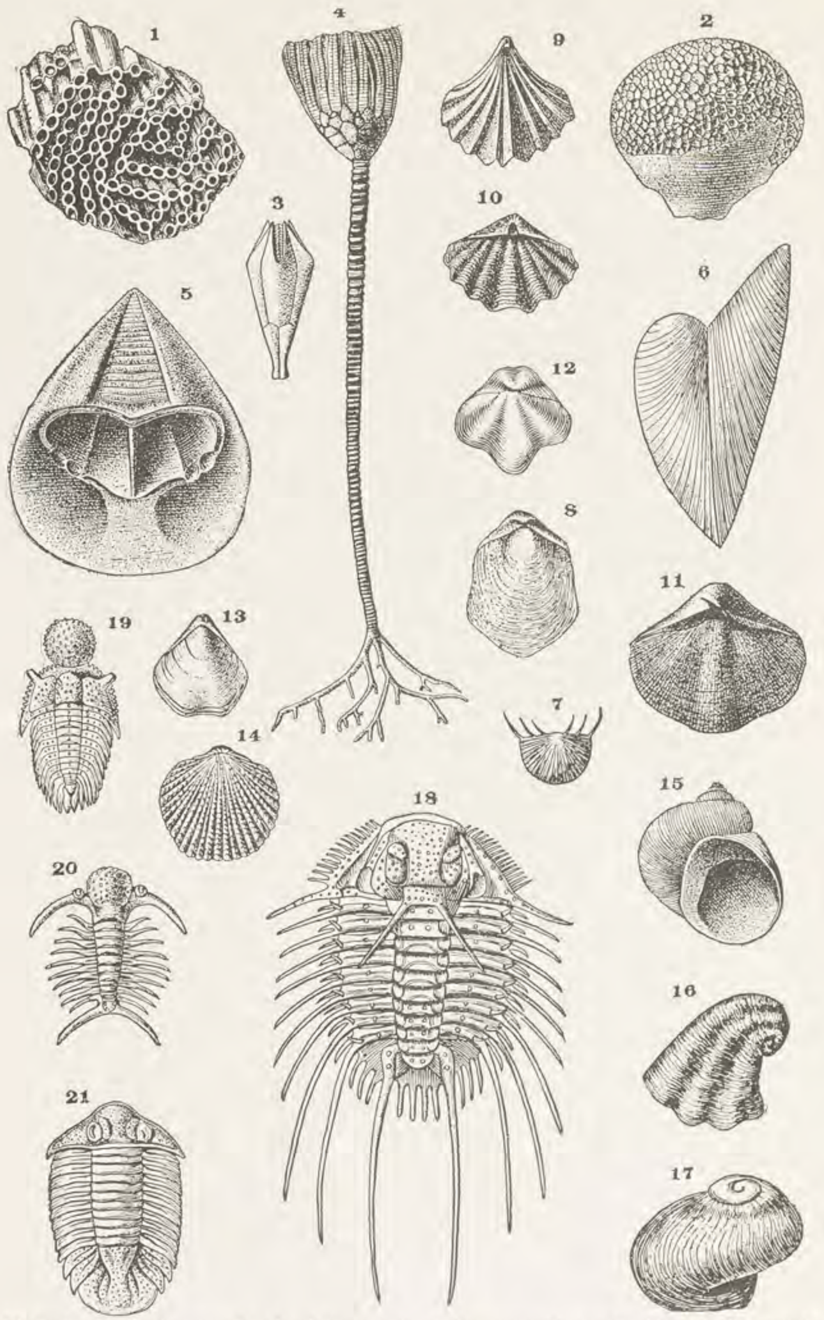

Plate 9. — Silurian corals (1, chain coral; 2, honeycomb coral), blastid (3), crinid (4), brachiopods (5–14), gastropods (15–17), and trilobites (18–21).

Fig. 1, *Halysites catenulatus;* 2, *Favosites occidentalis;* 3, *Troostocrinus reinwardti;* 4, *Eucalyptocrinus crassus;* 5, 6, *Monomerella noveboracum;* 7, *Chonetes cornutus;* 8, *Pentamerus oblongus;* 9, *Rhynchotreta americana;* 10, *Spirifer crispus;* 11, *S. radiatus;* 12, *Hyattidina congesta;* 13, *Whitfieldella nitida;* 14, *Atrypa nodostriata;* 15, *Strophostylus cyclostomus;* 16, *Platyceras angulatum;* 17, *Diaphorostoma niagarense;* 18, *Ceratocephala dufrenoyi;* 19, *Staurocephalus murchisoni;* 20, *Deiphon forbesi;* 21, *Metopolichas breviceps.*

Mainly after the New York and Indiana State Surveys. Also from Scott and Zittel.

Throughout the Silurian, but more particularly in the later part of the period, the eurypterids or so-called "sea scorpions" were common (see Fig. 337, 1–3); they were, however, not scorpions. They usually occur in brackish-water deposits that otherwise are devoid of fossils (cement rocks). The largest American species is found in New York (*Pterygotus buffaloensis*), where it reached a length of nearly 9 feet.

The most notable advance in Silurian life was the *first appearance of air-breathing land animals*. These were true scorpions and in general structure very much like those living to-day (see Fig. 337, 4, 5). Other air-breathing animals were the thousand-legs (myriapods) found in the late Silurian of Wales in association with eurypterids. Land plants were now more common, and there was a considerable variety of fresh-water fishes. From this time onward, in fact, we shall see wider and wider home-making on the dry lands by the emerging life of the rivers.

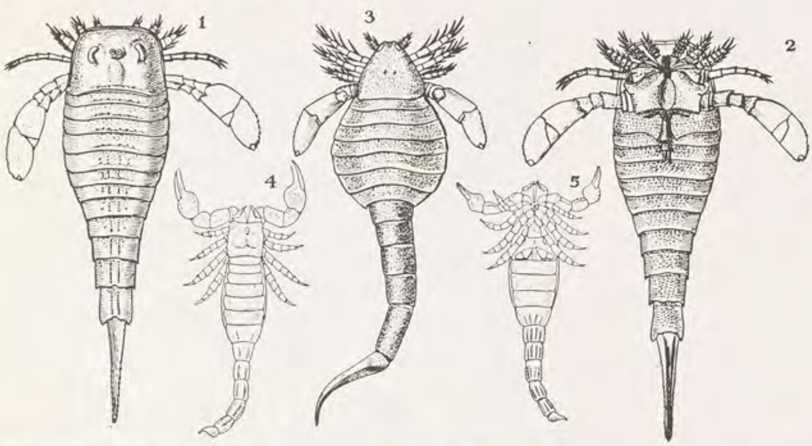

Fig. 337. — "Sea scorpions" or eurypterids (1–3) and scorpions. 1, 2, *Eurypterus remipes;* 3, *Eusarcus scorpionis;* 4, *Palæophonus nuncius;* 5, *P. hunteri.*

Corals. — Primitive corals, although present early in the Middle Champlainian, did not become common until the Middle Silurian, and then at many places in North America they made reefs, the best examples of which are seen in Wisconsin, Iowa, and the Manitoulin Islands. The animals that build these reefs are usually very small (under one-fourth of an inch), though their colonies may be 4 feet across.

The Paleozoic corals fall into two groups, the primitive Tabulata, and the true corals or Tetracoralla. The Tabulata are always colonial. The individual polyps are as a rule very small, but they build more or less long longitudinal tubes that are abundantly partitioned by tabulæ and perforated by pores as the

animals grow upward (see Fig. 338). Of these colonial forms, the chain coral (*Halysites*, Pl. 9, Fig. 1) was characteristic of the Silurian and the Champlainian, and the honeycomb corals (*Favosites*, Pl. 9, Fig. 2) were great reef makers in the Silurian and Devonian, where some of the colonies had a diameter of 4 feet. The

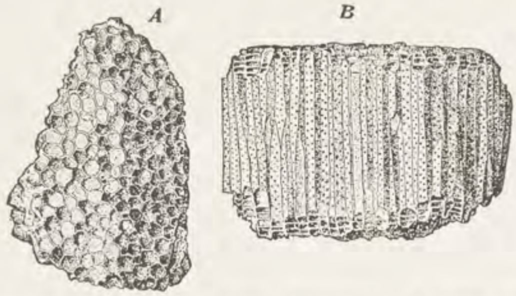

Fig. 338. — Tabulate or honeycomb coral (*Favosites*). *A*, from the top; and *B* from the side, to show transverse partitions (tabulæ) and small mural pores.

organpipe coral (*Syringopora*) was common throughout the Silurian and most of later Paleozoic time.

The tetracorals lived either in colonies or singly. They were very simple animals, with a single internal cavity, the wall of which was bent inward in the form of longitudinal folds or ingrowths. When one of these animals is cut trans-

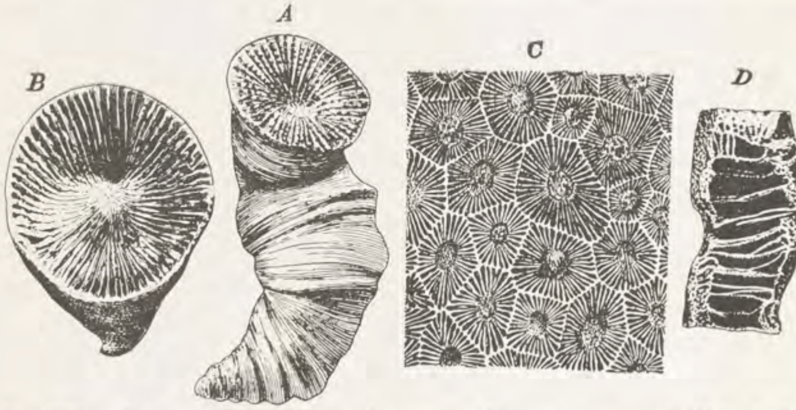

Fig. 339. — Paleozoic Tetracoralla. *A*, common Devonian cup coral (*Heliophyllum halli*); *B*, Silurian cup coral (*Zaphrentis umbonata*); *C*, a colonial type (*Cyathophyllum rugosum*); *D*, Devonian cup coral, sectioned to show internal tabulæ (*Amplexus yandelli*). After Rominger.

versely, these folds or partitions (septa) are seen as radii. The single polyps were cylindrical or conical in shape, and are known as cup corals; the group as a whole takes its name from the fact that the septa are arranged in four quadrants or bundles. The hard supporting skeleton was made of calcium carbonate, and it is this skeleton that is preserved to us, showing the exact shape of the body and the radiating partitions (see Fig. 339). The tetracorals were common through-

out the Paleozoic after Middle Champlainian time, but became rare in the Pennsylvanian and passed out of existence with the Permian.

After the Paleozoic and up to the present time the common types of corals are the Hexacoralla, so called because they start with six primary partitions and all subsequent cycles of partitions are regularly introduced between the previous ones. They are also reef-makers, but live singly as well, although the single polyps are not so decidedly cup-shaped as in the Tetracoralla.

CHAPTER XXVIII

DEVONIAN TIME AND THE DOMINANCE OF THE FISHES

There is no more significant or picturesque period in the history of the earth than the Devonian. This is the time when the former nakedness of the lands becomes clothed with a deeper verdure and the first forests appear, providing the needed homes and food for the invasion of the continents by the ever-hungry denizens of the rivers and seas. This invasion of the land is fairly under way in the Devonian, chiefly in the rivers and lakes, but due to the wide-spread arid climates a fierce struggle is instituted among the inhabitants of the then temporary waters, resulting in the dominancy of the better equipped air-breathing fishes, an issue prophetic of vertebrate ascendency upon the lands, hereafter never to be questioned in its onward sweep to its culmination in man.

Devonian Seas. — During the early Devonian, not more than 10 per cent of North America was covered with marine waters (see Pl. 10, Map 1). These seas were long and narrow in the Appalachic, St. Lawrencic and Cordilleric geosynclines. Late in the Lower Devonian the submergence became markedly general and attained its maximum flood in the late Middle Devonian (Hamilton time), when at least 38 per cent of the continent was covered by the sea (Pl. 11). The waters were warm, for they brought from the Gulf of Mexico and down the St. Lawrence many coral species which built extensive reefs. Later there was also an arctic invasion through the Cordilleric sea, and it likewise brought an abundance of corals, this being particularly true for Alaska and the Mackenzie Valley.

The longest sequence and the thickest series of Devonian deposits occur in the northern Appalachian area, where most of the materials are shales and fine-grained sandstones. The Catskills on the west side of the Hudson River are the most imposing single Devonian pile in the United States. The greatest thickness is in Pennsylvania, where the Susquehanna River has cut through the Appalachian Mountains; here a maximum depth of nearly 13,000 feet of Devonian shales and sandstones occurs, becoming increasingly coarser, less marine, and more rapid in accumulation with the progress of time, that is, toward the top. Along with the greater rapidity of accumu-

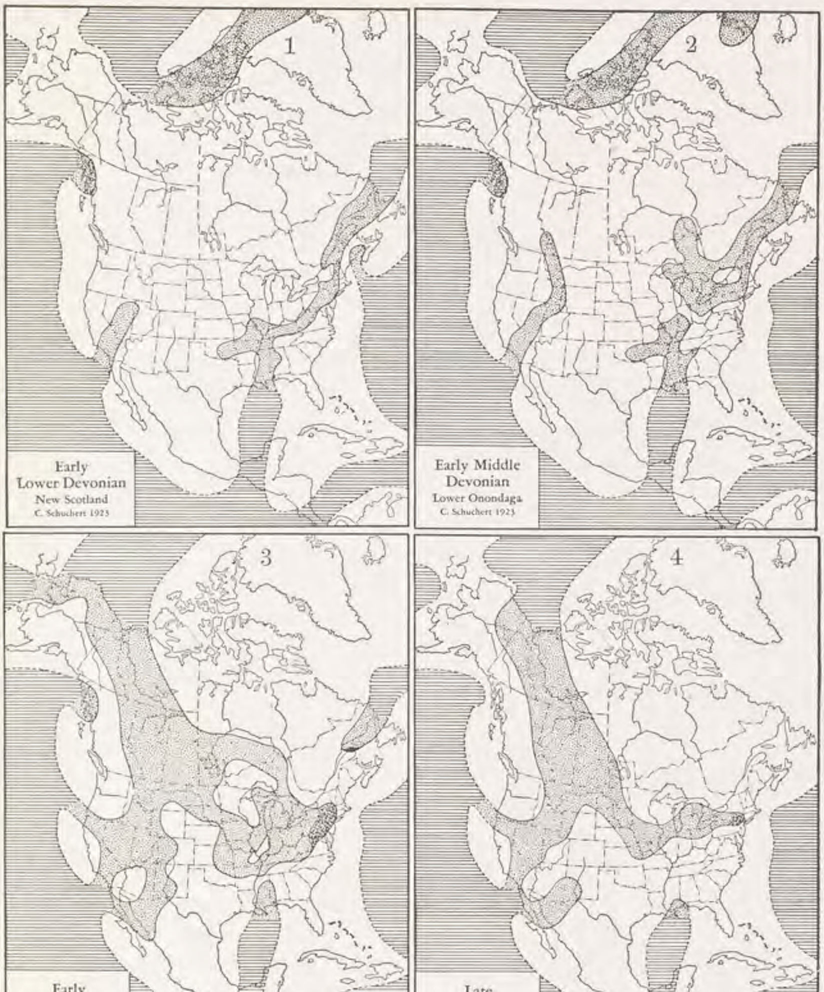

Plate 10. — Paleogeography of Devonian time.

Epeiric seas dotted; oceans ruled. See Plate 11 for late Middle Devonian physiography.

In Devonian time there was but one slowly developing flood, coming from the Arctic Ocean with Euro-Asiatic faunas and attaining maximum spread as depicted in Plate 11 and Map 3 of this plate, with slow recession in Map 4. Note in Map 3 the vast Appalachian delta and the much smaller one of Gaspé, Quebec; also the final absence of seas in the southeastern states.

lation the marine faunas become increasingly scarcer upward in the section, and the sediments change in character to red beds, most of which are of fresh-water origin, marked by ripples, sun-cracks, and rain prints, and having land plants and fresh-water fishes. Pennsylvania was the central area of a great delta formed at the mouth of the large rivers that flowed out of the highlands to the east and northeast, in which latter region there was mountain making and volcanic activity throughout much of the time of the delta accumulation. From this central and rapidly subsiding delta, the deposits thin rapidly to the north, west and south. Another big Devonian delta is represented at Gaspé on the end of the peninsula bordering the St. Lawrence River on the south. (See Pl. 11.)

During the Upper Devonian the seas were gradually withdrawn, earliest in the southern Mississippi valley, then throughout the interior of the continent, and lastly in the Cordilleran area. If there was any Devonian water finally left on the land, geologists have as yet failed to discern the transition strata between the Devonian and the Mississippian.

Acadian Disturbance. — The Acadian land, throughout the New England States and the Maritime Provinces of Canada, began to be elevated and folded in late Middle Devonian time, and here also the sea was finally completely in retreat throughout the entire area, destroying forever the seaways that formerly connected the Central Interior sea with the St. Lawrencic trough. This mountain-making movement has been named the Acadian Disturbance; it continued to the end of Devonian time, since even the Upper Devonian strata of continental character are folded. Throughout the whole period, and especially in the latter part of it, volcanic activity occurred here on a large scale, many of the lavas and intruded granites being preserved in the Maritime Provinces. The volcanic cones are now eroded away, and what is left are the deeper seated volcanic necks, one of which is Mt. Royal, back of McGill University, Montreal, and others the Monteregian hills farther east. Far greater intruded masses are to be seen, however, in many places throughout New Brunswick and southern Quebec, and there are great granitic bathyliths at St. George and in the Little Megantic Mountains. Possibly also the crystalline rocks of the White Mountains of New Hampshire and certain others of Vermont and Maine are of Devonian origin. With this folding, the rivers of Acadis were rejuvenated, marked erosion set in, and the resulting detritals (muds and sands) were carried into the Appalachian delta described above.

In Europe, we have seen that the Caledonian Disturbance toward

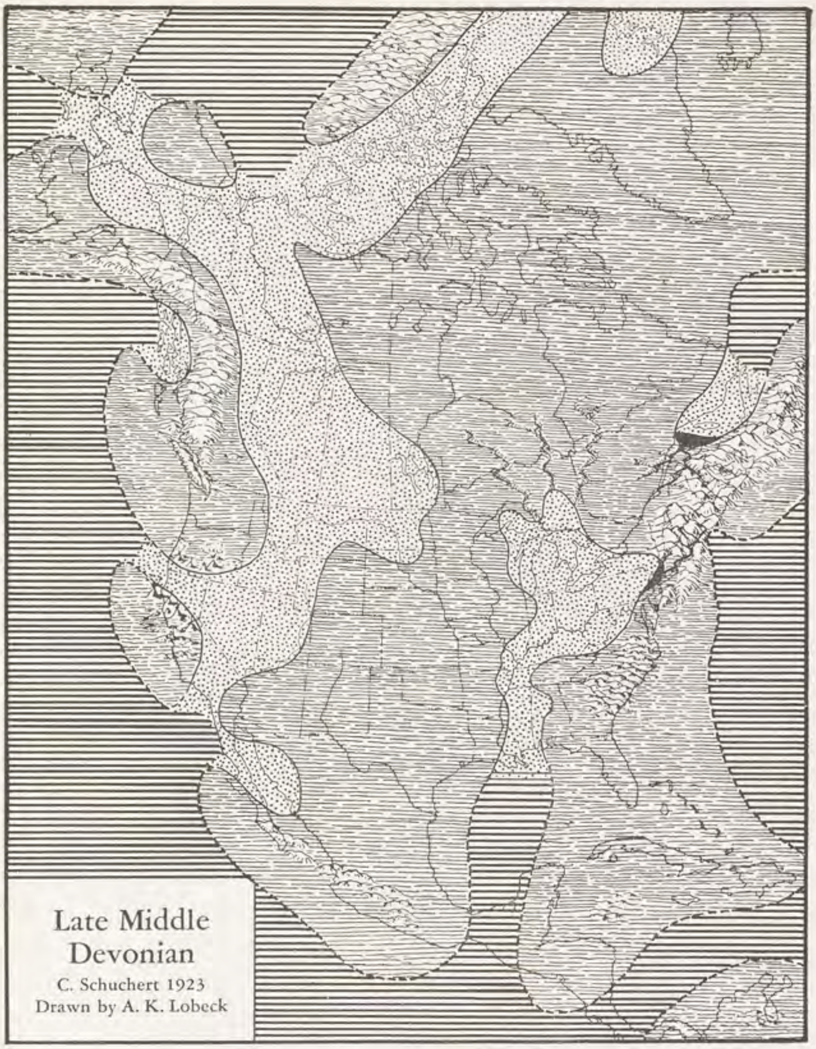

Plate 11. — Late Middle Devonian paleophysiography.

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 10 for Devonian paleogeography.

The probable geography of late Middle Devonian time, when the Acadian mountains were rising (see p. 536), from which came the main mass of sediments in the great Appalachian delta and that of Gaspé (black areas), described on page 536. The other highland areas are hypothetic, and even though the drainage is unknown, some rivers have been sketched in. Note the volcanoes in California.

The lands were clothed with vegetation and in the lowlands there were forests, with trees up to 35 feet in height (p. 542).

the close of the Silurian resulted in the making of mountains that extended throughout its northwestern portion. It was then that Laurentis (Canadian Shield-Greenland) was welded upon Baltis (Sweden-Finland), forming the most western part of a great northern transverse land, known as Eris. Asia

Devonian Fresh-water Deposits. — The oldest known fresh-water deposits of Paleozoic time with an abundance of fossils are those of the Devonian, and especially of the Old Red Sandstones of Scotland. From this time onward, the geologic record often bears testimony to the continental origin of certain deposits and their entombed life.

The Old Red deposits of Britain are a tremendously thick series of coarse detritals and volcanic effusives, seemingly accumulated under a desert climate in valleys between high mountains that were upheaved during the Caledonian Disturbance. Their maximum thickness may be as great as 37,000 feet, though in no single area is there more than 20,000 feet. These deposits are often very decidedly cross-bedded, and the materials are usually poorly assorted. The conglomerates are frequently of great thickness, with broken blocks as large as 8 feet in diameter. Ripple-marking is frequent, and the sun-cracking is deep, indicating that there was long exposure to dry air. There are also rain-drop impressions. All of these are characteristic of continental deposits. While the rocks are not red throughout the Old Red series, this is nevertheless the dominant color; it is usually due to the quartz grains being coated and held together by a crust of earthy ferric oxide. Some of the red sandstones of Scotland are often full of desert sand grains, and are highly false-bedded in places, like desert sand-dunes.

In America there are no Devonian strata that were accumulated in inland mountainous areas, like those of Scotland. They are, rather, delta deposits formed by large rivers flowing into the sea, apparently also under an arid climate. Certain of the Upper Devonian formations of New York (Oneonta and Catskill) and the sandstones of Gaspé are held to have been laid down in great coastal lagoons receiving terrigenous sediment rapidly and in vast quantity from a rapidly rising highland. It is in these regions that are found the American Old Red fishes, which appear to have come from the rivers and not from the sea.

Life of the Devonian

The seas after Lower Devonian time swarmed with corals, and with brachiopods and other shellfish, and in general the life was not very unlike that of the Silurian. The corals were wide-spread,

ranging from Louisville, Kentucky, north into Alaska. Of echinoderms, the blastids (p. 548) were now common and may have originated in America. Trilobites were still common, but greatly reduced in variety (see Pl. 12, Figs. 21–24). Especially characteristic of the Devonian were the brachiopods (Pl. 12, Figs. 5–12).

With the Devonian, the marine fishes first came into prominence, and their rise was accompanied by the decline of the trilobites and the nautilids, upon which they probably fed. The most striking fishes were the highly armored types (Arthrodira, Pl. 13, Fig. 4).

The fresh waters of Devonian time must also have abounded in life, an inference justified by the fact that over one hundred species of fishes alone, in more than forty genera, are known in the continental deposits of this time. The oldest forms were small spinous sharks known as acanthodians (see Pl. 13, Fig. 3). Various kinds of ganoids (Pl. 13, Figs. 6, 7), fishes related to the living sturgeons and gar-pike, were the common fresh-water forms, and there were also many lung-fishes or dipnoans (Pl. 13, Fig. 5). The group which has probably aroused more speculation than any other is that of the curious aberrant "winged" fishes known as Ostracodermi, which lived in the rivers (Pl. 13, Figs. 1, 2).

Of vertebrates higher than the fishes, the only evidence rests upon one foot imprint (*Thinopus*), nearly 4 inches long, which was found near the top of the Upper Devonian of western Pennsylvania (Fig. 340). This indicates the presence of a salamander-like animal with a probable length of nearly 3 feet.

Fig. 340.— The oldest known amphibian footprint (*Thinopus antiquus*), from the Upper Devonian of Pennsylvania, one half natural size. I and II are fully formed toes, III a budding toe, IV probably a rudimentary toe. Original at Yale University. After Lull.

Plants and the Climate. — In the Devonian there is much evidence of land plants, but it is not until the Middle Devonian that we can speak of assemblages of plants, or floras, for in the early part of the period these fossils are still very scarce. In the upper third of Devonian time there was a considerably diversified flora, forming the oldest or first forest, in which flourished fern-like plants, fern-like trees (*Psaronius*), rushes, tall ground pines (lycopods), and primitive evergreens with woody trunks nearly 2 feet in diameter (see Fig. 341). Drifted logs of these trees are often found in the marine

Plate 12. — Devonian corals (1, 2), blastids (3, 4), brachiopods (5–12), lamellibranchs (13–17), goniatites (18–20), and trilobites (21–24).

Fig. 1, *Heliophyllum halli;* 2, *Cystiphyllum vesiculosum;* 3, *Pentremitidea filosa;* 4, *Granatocrinus leda;* 5, *Chonetes setigerus;* 6, *Productella hirsuta;* 7, *Tropidoleptus carinatus;* 8, *Spirifer pennatus (mucronatus);* 9, *S. medialis;* 10, *S. arenosus;* 11, *Ambocœlia umbonata;* 12, *Athyris spiriferoides;* 13, *Pterinea flabellum;* 14, *Actinodesma erectum;* 15, *Orthonota undulata;* 16, *Goniophora carinata;* 17, *Grammysia bisulcata;* 18, *Aphyllites vanuxemi;* 19, *Manticoceras oxy;* 20, *Brancoceras sulcatum;* 21, *Odontocephalus selenurus;* 22, *Cryphæus punctatus;* 23, *Dipleura dekayi;* 24, *Phacops bufo.*

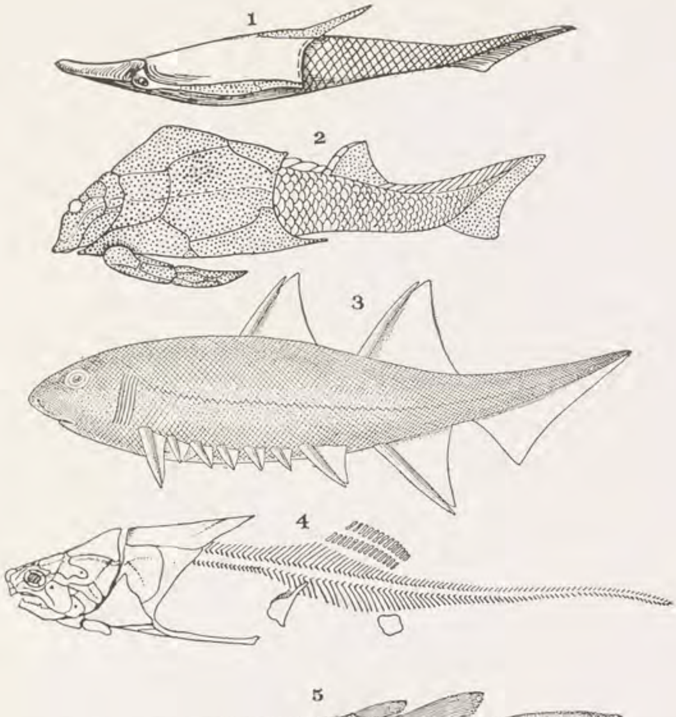

Plate 13. — Devonian Marine and Old Red Sandstone fishes.

Primitive armored fishes or ostracoderms (1, 2), primitive fresh-water shark or acanthodian (3), "terrible fish" or marine arthrodire (4), lung-fish (5), and ganoids (6, 7). Fig. 1, *Pteraspis rostrata;* 2, *Pterichthys milleri;* 3, *Climatius macnicoli;* 4, *Coccosteus decipiens;* 5, *Dipterus valenciennesi;* 6, *Osteolepis macrolepidotus;* 7, *Holoptychius flemingi.*

deposits of Upper Devonian time. At Gilboa in the Schoharie Valley, New York, have been found more than thirty great stumps and spreading roots of tall trees still standing in their native soil. These trees attained a height of 30 to 40 feet, and are thought to have been seed-ferns. For a further discussion of these ancient plants, see Chapter XXXII.

One of the most remarkable facts in connection with this flora was its wide distribution and uniform character throughout eastern

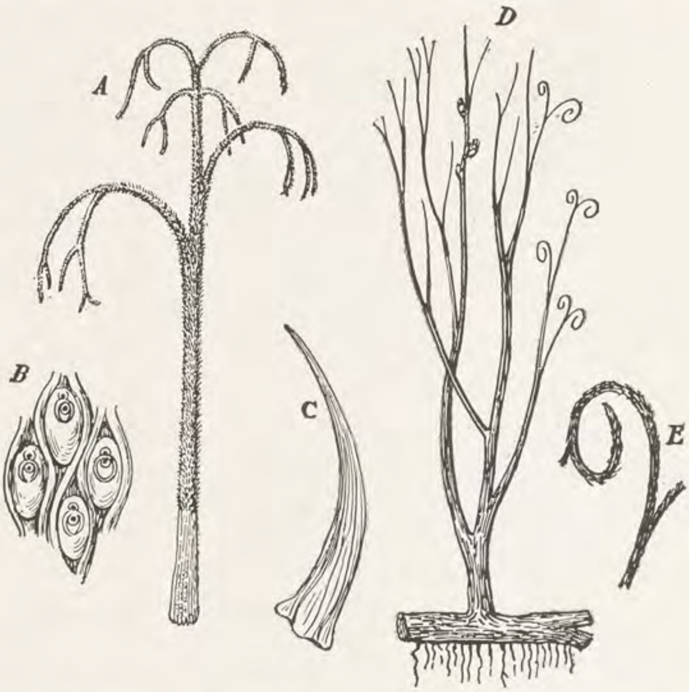

Fig. 341. — Restored land plants of the Devonian. *A*, lycopod tree (*Protolepidodendron primævum*) from the Portage of New York, height as restored in New York State Museum about 20 feet; *B*, leaf bases, and *C*, needle-leaf of same tree; *D*, a very primitive plant (*Psilophyton princeps*) attaining a height of several feet, as restored by Dawson with fructifications. *E*, terminal branch of same, enlarged.

North America and into the Arctic region, Spitzbergen and northwestern Europe, indicating equable climates and the complete union of North America and Europe across Greenland, Spitzbergen, Norway and Great Britain. None of the trees show annual rings of growth attesting to seasonal changes due to a varying climate or to prolonged drought, and it is held that the general climate of this

time was uniformly warm though semiarid, the known forests being localized in wet places along the valleys and in the swamp areas near the sea front. That the climate was warm is further shown in the wide distribution of the reef corals of the seas, which extended even into arctic regions, but that the air was more or less semiarid is proved further by the prevalence of the oxidized and red continental deposits of Eris.

CHAPTER XXIX

THE MISSISSIPPIAN PERIOD AND THE CLIMAX OF ANCIENT SHARKS

The Upper Paleozoic rocks were originally regarded as comprising but a single period of time, and because coal (carbon) is common in them, they were called the Carboniferous System. In western Europe, where Geology had its inception, the coal-bearing strata are of wide occurrence, and in England the miners have long used the term "Coal Measures." At present the Europeans recognize two systems, Carboniferous (Lower and Upper) and Permian, while in America three are now accepted, namely, Mississippian, Pennsylvanian and Permian.

The geologic record of Mississippian time in North America is markedly different from that of the succeeding Pennsylvanian, for the former is chiefly of the sea, while in the latter in the eastern half of the continent there is an alternation of the sediments of marine floodings with accumulations of coal beds in vast more or less fresh-water swamps. In other words, the Mississippian is a recurrence of Devonian conditions, while the Pennsylvanian formations alternate between those of the sea and land.

Eastern North America during the Mississippian was bordered as before by greater Appalachis, and as this old land had been re-elevated at the close of the Devonian (Acadian Disturbance), it was natural that the shallow seaways to the west of it as far as the Cincinnati arch should be depositing much mud and sandstone and but little limestone. In the Mississippi valley the small seaways had, as a rule, clearer water, and here the dominant rocks are limestones and oölites, although the period opens with black muds. Along the Pacific coast was the old land Cascadis, and to the east of it lay a wide shallow sea depositing in the main limestones. At times this sea connected with the marine waters of the Mississippi valley.

Toward the close of the period, mountains arose in several places as will be shown later, separating the Mississippian from the Pennsylvanian. Within the period there was also wide-spread retreat of the seas, especially in western North America, and the Mississippian,

therefore, separates into two epochs, Early Mississippian or Waverlian time, and Late Mississippian or Tennesseian time.

Waverlian Time. — The submergence of Waverlian time (named from Waverly, Ohio) began in the Gulf States and along the western side of the Cincinnati uplift. The seas were at first small in extent, but later were greatly expanded on either side of the above-mentioned axis and in the Appalachic trough. In the Acadian area of New Brunswick and Nova Scotia there was another basin of deposition, but with strata wholly of fresh-water intermontane character. The most striking change of this time, however, was the reappearance of the Cordilleric sea, depositing far and wide throughout the Rocky Mountains a great mass of limestone, known as the Madison limestone, through which in many places deep and picturesque canyons have been cut, as, for example, the Grand Canyon of the Colorado. This Cordilleric sea is also known in Alberta and on the Liard River in the Mackenzie region, and probably extended into the Arctic Ocean. That it connected at times with the Central Interior sea either across Colorado or New Mexico into Kansas and Oklahoma, is proved by identical species in both; in fact, more than one-third of the Cordilleran forms also occur in the Central Interior sea. The Cordilleric waters vanished completely at the close of this first epoch, to reappear, greatly altered in geography, in the succeeding Tennesseian epoch. During the maximum submergence of Waverlian time about 26 per cent of North America was under the sea.

Tennesseian Time. — The seas of early Tennesseian time began a renewed spread in the Central Interior area and attained their maximum toward the close of this epoch. It appears that never was more than 12 per cent of the medial portion of North America submerged, while the average for the epoch may have been about 8 per cent. Nowhere are there more than 1100 to 1800 feet of sediments, most of which in the center of the area are limestones and oölites. On the flanks, and especially along southern Appalachis, there are sandy or calcareous marine shales that attain a thickness of several thousand feet, but the deposits in the northeastern part of the Appalachic trough are, in the main, of continental origin, being soft, red, sandy shales devoid of marine fossils (Mauch Chunk).

In the Acadian area there was another sea of this time, consisting of narrow connected troughs between mountain ranges made during the Acadian Disturbance. These seaways deposited conglomerates, sands, much mud, thin zones of dolomites, and great quantities of gypsum, that together have an estimated thickness of 2000 feet.

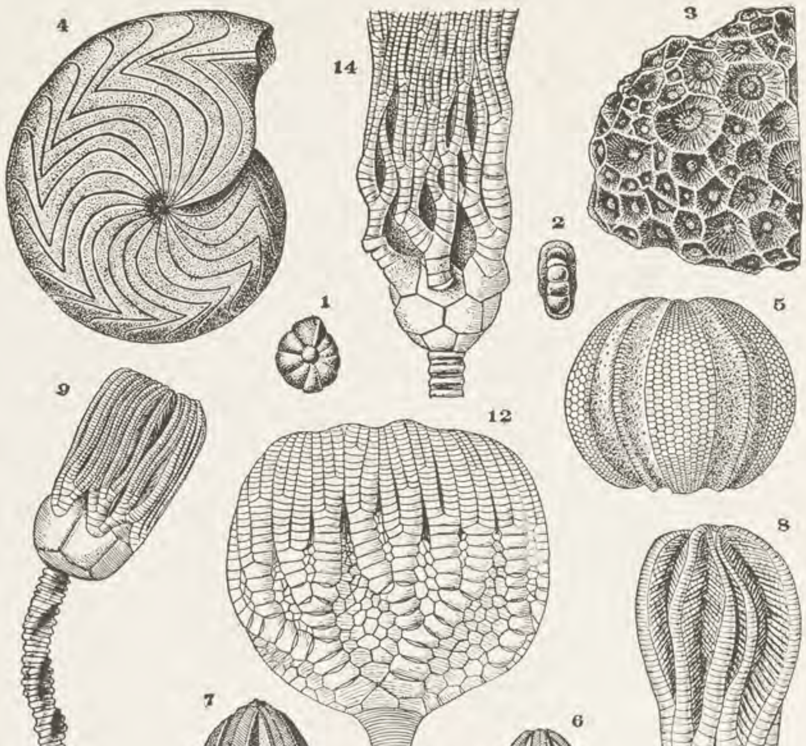

Plate 14. — Mississippian Protozoa (1, 2), reef-coral (3), goniatid (4), sea-urchin (5), blastids (6, 7), and crinids (8–14, 9–11 camerate).

Figs. 1, 2, *Endothyra baileyi;* 3, *Axinura canadensis;* 4, *Brancoceras ixion;* 5, *Melonechinus multiporus;* 6, *Pentremites conoideus;* 7, *P. elongatus;* 8, *Agassizocrinus dactyliformis;* 9, *Platycrinus symmetricus;* 10, *Batocrinus pyriformis;* 11, *Agaricocrinus bullatus;* 12, *Forbesiocrinus wortheni;* 13, *Onychocrinus ramulosus;* 14, *Cyathocrinus multibrachiatus.* In the main after the Indiana State Survey.

The fauna is a distinct one, with English affinities, and has no close relationship to those of other American seas.

In the Cordilleran area the late Tennesseian formations have Pacific faunas, and south of Colorado the trough still remained very wide, the narrowing here not taking place until the close of the Pennsylvanian.

Ouachita-Cahaba Disturbance. — In the southern Appalachic geosyncline of central Alabama (Cahaba coal field), there are at least 10,000 feet of coarse deposits, conglomerates and sandstones, all of which are either of latest Tennesseian or earliest Pennsylvanian age. A similar series (Stanley-Jackfork), having a maximum thickness of over 12,000 feet, was laid down along the south side of the Arkansas valley, extending into southeastern Oklahoma, that is, in the area of the Ouachita Mountains. These great thicknesses of detritals show that in southwestern Appalachis and in northeastern Llanoris, mountains of no mean altitudes had been in existence during late Tennesseian time. These orogenic movements, known as the Ouachita-Cahaba Disturbance, and resulting in a greatly changed geography of the Central Interior seas and a consequent long emergent time, separate the Tennesseian from the Pennsylvanian.

Windsor Disturbance. — In Nova Scotia and New Brunswick, the Cheverie and Windsor, and all of the older formations as well, were toward the close of the Tennesseian also folded into a high series of mountains (= Windsor Disturbance). Mountains were also made at this time in Great Britain and Germany.

Life of the Mississippian

In Middle Waverlian times the life of the seas was most diversified, and there was an abundance of crinids (see below) in great variety, a richness of development never attained before or afterward by this class of animals. In the Tennesseian, however, the crinids were far less diversified. Other kinds of invertebrates abundant in the Mississippian seas were the bryozoans, cup corals, and brachiopods; one brachiopod genus, *Productus* (Pl. 16, Figs. 5–11), was, in fact, so common and conspicuous in the seas of all three Carboniferous periods that they are often called Productus seas. Among cephalopods, the nautilids were no longer so prevalent as they were in earlier times. Their descendants, the goniatites (Pl. 14, Fig. 4) were now rising into ascendency and were more common than in the Devonian, but this statement applies rather to the European seas than to the Central Interior sea. Trilobites were almost gone.

In the Tennesseian, two groups of echinoderms were especially well developed. These were the blastids (*Pentremites*) described below, which are the guide fossils to the marine deposits of this time, and in places are so common that geologists have called the beds the Pentremital limestones; and, associated with them, though far less common, the equally characteristic sea-urchins known as *Melonechinus* (melon-urchin, see Pl. 14, Fig. 5).

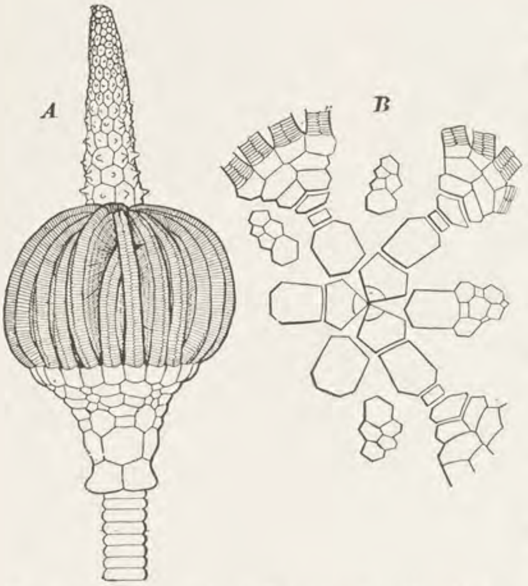

Fig. 342. — A box crinid (*Batocrinus pyriformis*) from the Mississippian of Iowa. *A*, stalk, calyx, arms, and anal tube, from the side. *B*, plates of calyx spread out to show shape and arrangement. After Keyes, Geol. Surv., Missouri.

Crinids (see Pl. 14, Figs. 8–14), also called feather-stars, belong to the spiny-skinned sea animals technically known as Echinoderma. They are distant relatives of the starfishes and sea-urchins, but are anchored to the bottom by a more or less long stalk instead of moving about freely as is the habit of the two latter groups. They are usually gregarious. They consist of three main parts: (1) the calyx or body, (2) the feathered arms, and (3) the stalk. In the Paleozoic, crinids were very common, especially the forms known as box crinids (Camerata, now extinct; see Fig. 342). In certain horizons in the Mississippian they occur in such abundance as to make limestones a hundred feet in thickness, called crinidal limestones.

Blastids (see Pl. 14, Figs. 6, 7) are small, stalked Echinoderma that arose in early Champlainian time. In a broad way, their fossils resemble nuts and because of this the people in the Southern States, where they are common, often call them "fossil hickory nuts." They are far more simply built than the crinids, and differ markedly in having no arms.

Large sharks of the shell-feeding type were becoming more and more plentiful during Waverlian time, for their flat, crushing teeth and large fin spines are often abundant, and especially so toward the close of this epoch (Keokuk time). In the American Devonian there are 39 species of shell-feeding sharks, in the Mississippian 288,

in the Pennsylvanian 55, and in the Permian 10. It is apparent, therefore, that there was a very rapid evolution of the sharks in the Waverlian, when they were the dominant marine fishes, with a quick

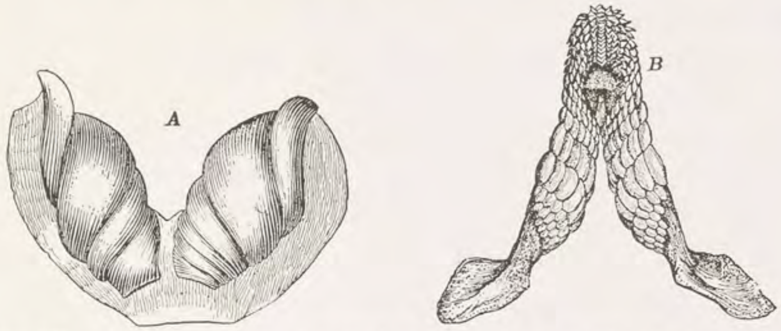

Fig. 343. — Cochliodont (*A*) and cestraciont (*B*) teeth of primitive sharks. *A*, jaw with two large tooth-plates (*Cochliodus contortus*). *B*, upper jaw, with many teeth, of Port Jackson shark (*Cestracion philippi*). British Museum (Natural History).

decline during the Tennesseian, the history being the same in Europe. These sharks were all of primitive types, and by far the most common were those with pavement-like teeth, known as cestracionts, and the cochliodonts (Fig. above).

CHAPTER XXX

THE PENNSYLVANIAN PERIOD, THE TIME OF GREATEST COAL MAKING

The outstanding features of the Pennsylvanian period are its variable geography, resulting in great coal-making swamps, and its abundance of coal-making plants. The period was especially one of crustal unrest. Previously during the Paleozoic the times of mountain making occurred at or toward the close of the periods, but during the Pennsylvanian the mountains were raised repeatedly. The seas, due to this marked instability of the earth's surface, oscillated back and forth over the low lands more actively than before. The climate was warm and genial the world over, and the lands bordering the epeiric seas were moist, with an abundant and well distributed rainfall. Under these conditions great fresh-water swamp areas developed, replete with a varied flora, which grew quickly and reproduced itself in the main through spores. These plants were buried in the swamps where they had lived, and accumulated there in such vast quantities as to make the greatest of the world's coal reserves.

The marine and fresh waters had an abundance of animal life, but of greater significance was the presence on the lands of air-breathers in plenty, from plants, snails and insects to amphibians and reptiles. It was still, however, an ancient organic world, but the prophecy of medieval times was upon it, and its unfolding was to begin in the next or Permian period.

Seaways (see Pl. 15). — The Pennsylvanian seas submerged great parts of the continent, coming from the southwest over Texas and Oklahoma and overlapping the land northward into Nebraska and eastward into Pennsylvania. The submergence was most extensive in middle Pennsylvanian time, when about 30 per cent of North America was again under the sea. During the greater part of the period, the sea-level in the eastern half of the United States was decidedly oscillatory, due to local warpings of the land, and here the Coal Measures are largely a series of interbeddings of shallow marine and brackish-water finer sediments with coarser ones of fresh waters. A final regression of the seas began late in the period, and they lingered longest west of the Mississippi and south of the Missouri

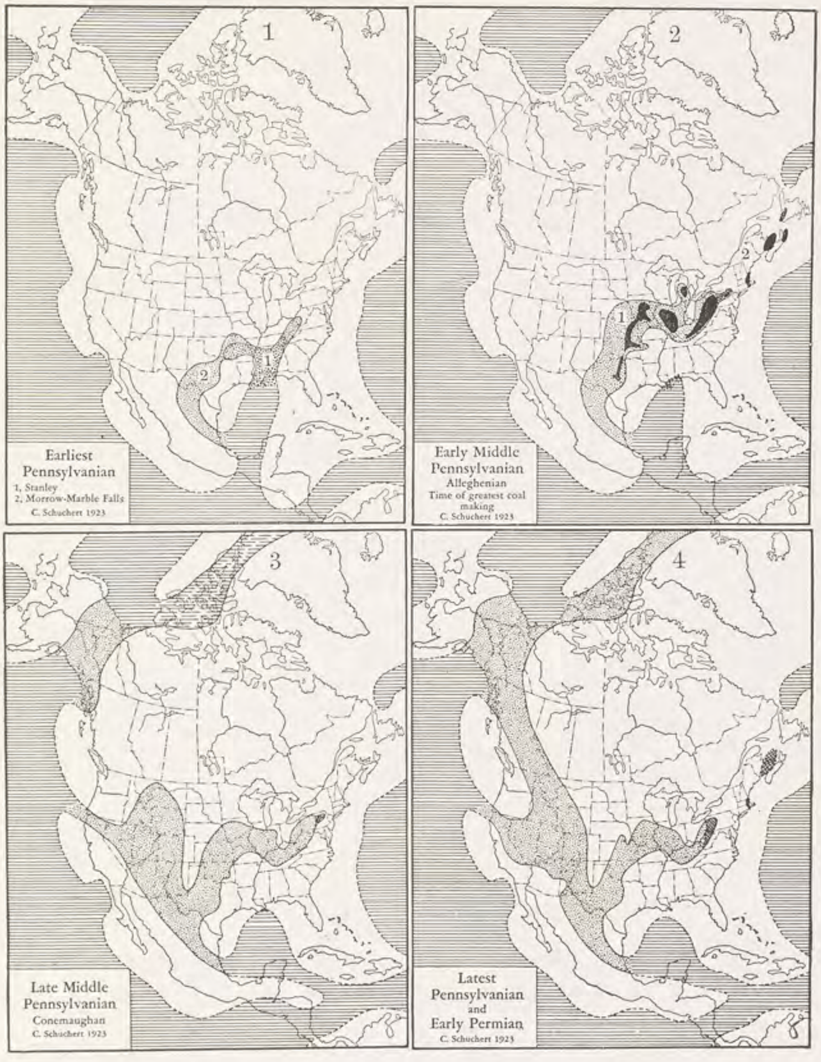

Plate 15. — Paleogeography of Pennsylvanian time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled; coal-making swamp areas in solid black. Note that the latter are in areas of the seas (1 = paralic coals), and in fresh-water basins of deposits (2 = limnetic coals).

Note the vanishing of the Appalachic geosyncline, and the spreading of the southern Cordilleric trough across Mexico. The former change is prophetic of the rising of the Appalachian Mountains, illustrated in Plate 17.

rivers, retreating more and more to the southwest in very latest Pennsylvanian time and continuing to retreat, but far more slowly, throughout the Permian.

Sediments. — The most striking feature of the Pennsylvanian strata in this country and Europe is the fact that they contain the greatest known accumulations of coal. In the Maritime Provinces of eastern Canada, the Pennsylvanian is well developed and usually of very great thickness. The celebrated Joggins section of Nova Scotia is 13,000 feet in depth and consists entirely of continental deposits, with some workable coal beds. The Cape Breton series is 10,000 feet thick and the Pictou field has a similar thickness; both of these regions also have valuable coal beds. It is very rare for marine fossils to be reported from this region.

In the Appalachic basin east of the Cincinnati arch, and in the greater Central Interior sea to the west of this axis and extending into Nebraska, Kansas, Oklahoma and central Texas, the formations have alternations of marine deposits with coal accumulations (see Pl. 15, Map 2). It was in these areas, therefore, that the sea-level was most oscillatory, and here workable coal occurs. In the Appalachic basin the mass of strata is not only thicker, but also coarser, consisting, in general, of sandy shales and sandstones with the marine and calcareous zones inconspicuous or locally absent, the marine zones vanishing eastward. Here also the coal accumulations are thicker, as the swamps were of greater areal extent, lasted longer, and were less often under the influence of the sea.

The essentially muddy and sandy marine deposits of Pennsylvanian time in eastern Kansas thin out into Nebraska and Iowa but increase southward into a tremendously thick delta series of sandstones and sandy shales that are almost devoid of workable coals. To the south and southeast, there then lay a high land of large dimensions known as Llanoris, from which these sediments came. West of Little Rock, Arkansas, into southeast Oklahoma occurs the thickest series of Pennsylvanian strata known anywhere in the world, with a depth of between 20,000 and 25,000 feet.

The fossiliferous marine condition of the later Pennsylvanian beds of Nebraska and Kansas gradually vanishes more and more toward Oklahoma, and the greater part changes into the widely known red beds of that state, Texas, and the southern Great Plains country (see Pl. 15, Map 4). With the appearance of the red deposits, not only do the marine fossils disappear, but tremendously thick beds of table salt and gypsum occur. On going south in Texas, the amount of gypsum becomes less, the red beds yield very interesting

amphibian and reptilian remains, and the time is toward the close of the Pennsylvanian or is Permian.

In the Cordilleran region, the record is very different from that of the eastern portion of the continent. In the area of the Rocky Mountains and the Great Plains, wherever Pennsylvanian formations are known, they are as a rule limestones of normal marine waters, and only in New Mexico and southeastern Colorado is there an alternation of this condition with that of coal making.

Along the Pacific border from northern California into arctic Alaska, the limestones and calcareous shales of the Pennsylvanian and early Permian are interbedded with much extrusive volcanic material. The calcareous deposits often abound in fossils unrelated to those found elsewhere in North America, showing that here the North Pacific faunas prevail.

Pennsylvanian Mountains. — The late Mississippian and Pennsylvanian periods were times of marked crustal movement, resulting in far-reaching changes in the distribution of land and sea. In central and western Europe, the movements began shortly after the close of Lower Carboniferous time, were renewed in the Upper Carboniferous, and again in the Permian. In the heart of Europe there arose a mighty chain of folded mountains, the *Paleozoic Alps of Europe*, whose stumps of massive rocks may be seen in Germany, France, Belgium, England and Ireland to-day; their general distribution is shown in the figure on page 387. Mountains also arose in the Pyrenees, the Spanish Meseta, Corsica, Sardinia and the Alps. The folding of the Urals likewise began in later Carboniferous time and attained its climax in the Permian. Even in Armenia, central and eastern Asia (Altai, Tianschan, etc.), and South Africa, Australia, and the Andes can be followed the traces of the mountain-making movements of this time. (See Fig. 344.)

Just as high mountains arose in western Europe shortly after the close of the Lower Carboniferous, so similar ones came into being in America at the end of the Mississippian. The ancient land Llanoris of Louisiana, Texas, Oklahoma and Arkansas was in movement early in the Pennsylvanian and again later in this period, while in Oklahoma arose the Arbuckles and Wichitas.

The coarse and thick deposits of the late Pennsylvanian and Permian in New Mexico, Colorado and Wyoming, known as the red beds, have recently been interpreted as the débris brought down from a newly arisen area to the east of them. These mountains, the *ancestral southern Rockies*, were also the source for most of the red beds of central Texas and Oklahoma, a region that in Pennsyl-

vanian time, however, was getting its sediments from the southeast or Llanoris. This orogeny completely changed the geography of the area of the southern Rocky Mountains, and different seaways with different faunas lay on either side of these mountains.

Along the Pacific border, the extrusive igneous material interbedded with the Pennsylvanian marine formations testifies to an abundance of volcanoes from northern California north into Alaska.

The region of New Brunswick and Nova Scotia of the Acadian area is a fine one to illustrate in intermontane marine and continental deposits a successive series of elevations. Here may be studied two movements that made for intermontane seaways, and four that

Fig. 344. — The ranges of mountains elevated toward the close of the Paleozoic: Appalachians, Andes, Paleozoic Alps of Europe, and others.

are recorded in fresh-water valley deposits. The first movement, toward the close of the Devonian, let in the sea only partially (Horton-Albert series); then came the second orogeny, bringing in the Windsor sea of late Mississippian time. This period was closed by a third time of mountain making, which blotted out in Acadis nearly all the seaways. In middle Pennsylvanian time came the fourth movement, and the fifth after this epoch. The sixth is of Permian time.

Coal and Petroleum. — Coal is a compact mass of plants, greatly altered through decay, the end result of which is mainly carbon. The first stage of accumulation and decay is the formation of peat, which is explained on pages 175–179. The transformation of peat

into the various kinds of coal is the result of dynamo-chemical processes resulting from deep burial and great pressures during long periods; these bring about the further escape of the gases and fats and leave greater and greater amounts of fixed carbon. Anthracite coal, for example, which has 90 to 95 per cent of fixed carbon, almost invariably occurs in regions where the strata are much squeezed and folded, as in the mountain sections of Pennsylvania; and where the strata are still more greatly deformed, as in the Rhode Island field, the coals are graphitic, consisting wholly of fixed carbon.

In 1912 the soft coal mined in the United States amounted to 450,000,000 short tons, valued at the mines at $518,000,000. The

Fig. 345. — Known distribution of coal in the United States. Black areas, coals of Pennsylvanian age, except in Virginia and North Carolina, where the eastern areas are of Triassic time. Areas with horizontal lines, in the Rocky Mountains country, coals of Cretaceous age. Areas with diagonal lines, coals of Cenozoic time. U. S. Geol. Surv.

anthracite output of Pennsylvania for the same year was 75,000,000 tons, valued at $177,000,000. In 1913 three-quarters of a million men were employed in the mining of coal. From 1814 to the end of 1900 the United States had produced 4,470,000,000 short tons of coal, and by the end of 1914 the total had risen to 10,358,000,000 short tons. The total amount of coal in the United States still within 3000 feet of the surface is estimated at about 3,540,000 million tons.

Petroleum and natural gas are mixtures of carbon and hydrogen, and are hence called hydrocarbons. They are the decomposition

Fig. 346. — Pennsylvanian flora and amphibia, as restored by J. Smit. In the background are seal trees (*Sigillaria*), with tree ferns and conifers in the middle distance. In the foreground are rushes (*Calamites*) and seed-bearing fern-like plants. Amphibia are represented by a small four-limbed microsaurian (*Keraterpeton*), a large-headed form (*Loxomma*), and a snake-like, gill-bearing stegocephalian (*Dolichosoma*, from Linton, Ohio). From Knipe's *Nebula to Man.*

residues of plants and animals that lived in bygone times, and mainly in the seas. Forming at the times when the marine strata originated, the hydrocarbons are stored away in solid form in muddy rocks and mainly in black shales. They are subsequently freed as liquids or gases from these mother oil strata by the waters of the earth's outermost shell which are circulating under great pressures, and by these waters are carried into porous or cavernous formations, mainly sandstones. Where the strata remain practically horizontal, petroleum and natural gas may be of any age younger than the Proterozoic, but where they are folded into mountains the volatile hydrocarbons in paying quantities are gone in rocks back of the Jurassic. The rocks storing the hydrocarbons are tapped by wells drilled into them at depths between 500 and 5000 feet or more.

In the United States the petroleum industry began in Pennsylvania in 1859 with a production of 2000 barrels. In 1920 the yield had risen to the astonishing sum of 450,000,000 barrels, and the annual yield of natural oil and gas is now worth not far from one billion dollars.

Life of the Pennsylvanian

With the Pennsylvanian, land plants began to be common, and the swamp floras were then luxuriant, large and varied (see Fig. 346). Furthermore, these floras, and the land animals as well, were not only very much alike in the different lands of the northern hemisphere, but there was a marked similarity even between the floras of the two hemispheres during the greater part of Pennsylvanian time. In other words, the floras, and to a lesser extent the faunas, were cosmopolitan, and their similarity was undoubtedly due to equable climates and easy migration across the extensive east-west continent Eris. Their distribution was further facilitated by the fact that most of the plants had spores, or microscopic reproductive germs, which could be widely blown about by air currents.

As a result of the warm climate and great development of the faunas, the Pennsylvanian was the time of giant insects, the largest ever known. The maximum size was reached by those of the dragon-fly type, one of which, found in the Coal Measures of Belgium, measured 29 inches across the wings. The period well deserves the title of the Age of Cockroaches, since more than 800 kinds are known from its rocks. They were mainly carnivorous, and as a rule large, several attaining a length of 3 to 4 inches.

In the Pennsylvanian rocks scorpions are found, which, ancient as they are, much resemble those of modern times. Associated

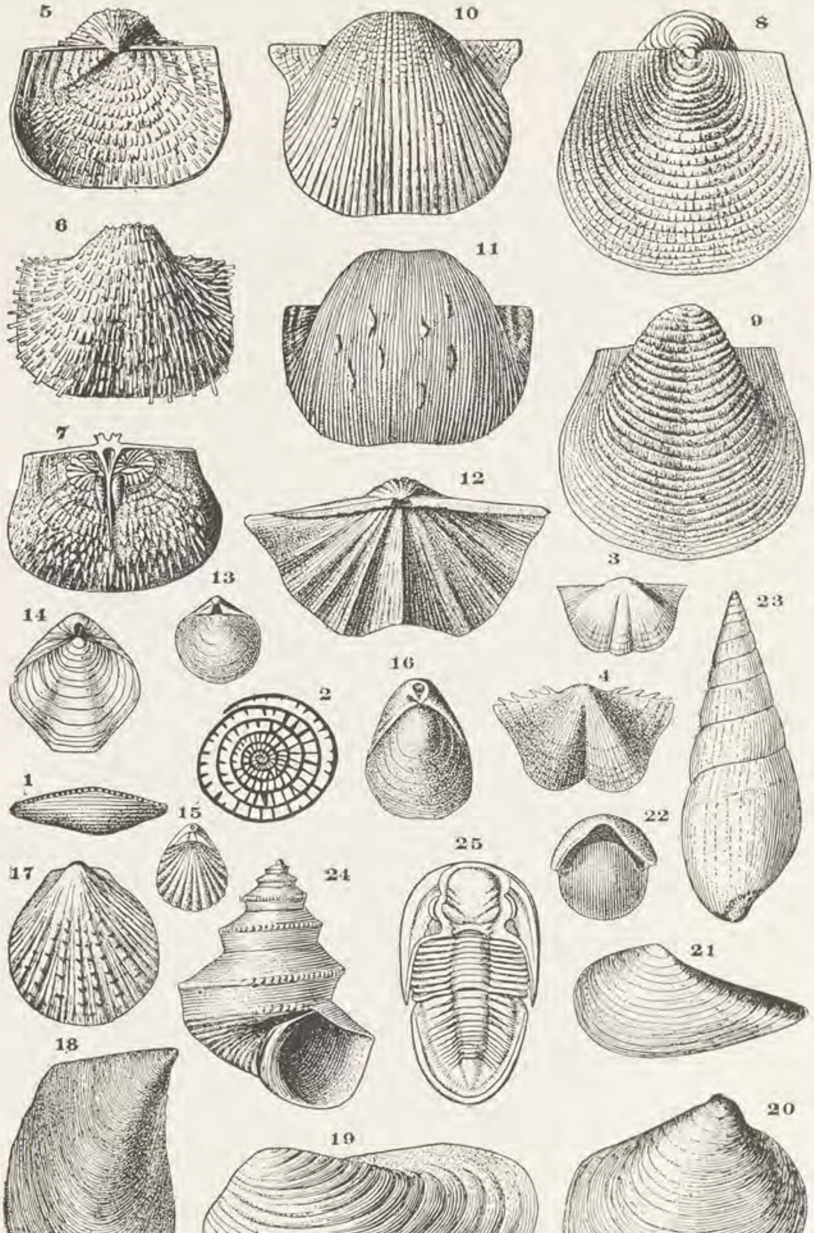

Plate 16. — Pennsylvanian Protozoa (1, 2, Fusulinidæ), brachiopods (3–16, 5–11 productids), bivalves (17–21), and gastropods (22–24), and one of the last trilobites (25).

Fig. 1, *Triticites secalicus;* 2, same cut through center; 3, *Chonetes mesolobus;* 4, *C. verneuilianus:* 5–7, dorsal and ventral valves, and dorsal interior of *Productus nebraskaensis;* 8 and 9, *P. punctatus;* 10, *P. semireticulatus;* 11, *P. cora;* 12, *Spirifer cameratus;* 13, *Ambocœlia planoconvexa;* 14, *Composita subtilita;* 15, *Hustedia mormoni;* 16, *Dielasma bovidens;* 17, *Pseudomonotis hawni;* 18, *Myalina subquadrata;* 19, *Allorisma subquadratum;* 20, *Schizodus harii;* 21, *Leda bellistriata;* 22, *Euphemus carbonarius;* 23, *Soleniscus fusiformis;* 24, *Worthenia tabulata;* 25, *Phillipsia major.* (558)

with them were many forms of thousand-legs and rather stout spider-like animals.

Of the higher kinds of animals, the vertebrates, there is evidence of the presence of many kinds of Amphibia (46 genera, see Fig. 346). Skeletal remains of the next highest class, the Reptilia, which were to dominate the lands in the following Permian period, are first found in the Upper Pennsylvanian.

In the marine waters of the Pennsylvanian, the invertebrate life was not only prolific but very varied (see Pl. 16). It was, moreover, cosmopolitan. Brachiopods are the common fossils in this country,

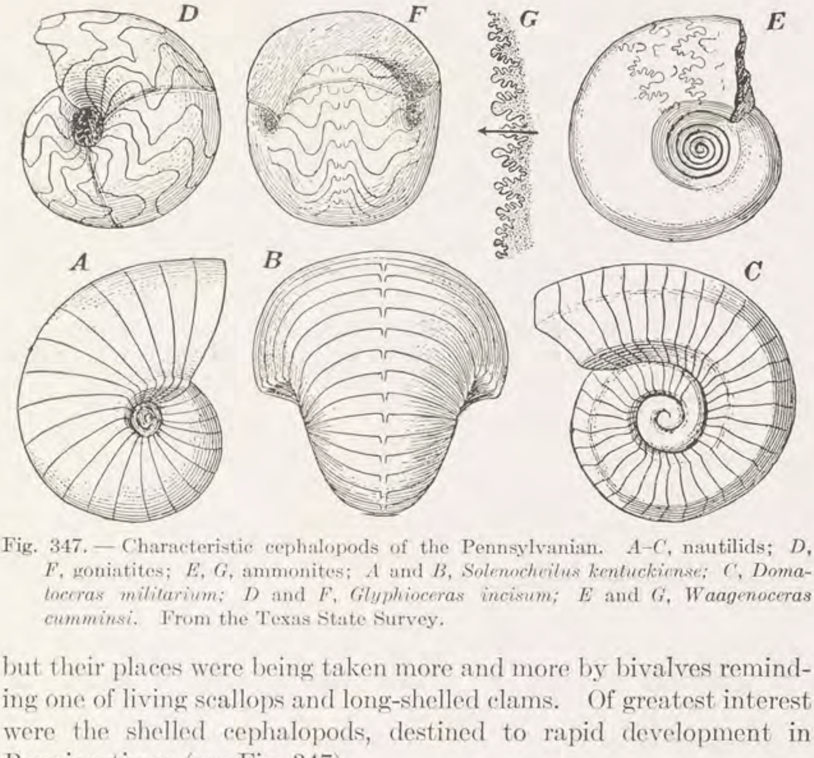

Fig. 347. — Characteristic cephalopods of the Pennsylvanian. *A–C*, nautilids; *D*, *F*, goniatites; *E*, *G*, ammonites; *A* and *B*, *Solenocheilus kentuckiense; C*, *Domatoceras militarium; D* and *F*, *Glyphioceras incisum; E* and *G*, *Waagenoceras cumminsi.* From the Texas State Survey.

but their places were being taken more and more by bivalves reminding one of living scallops and long-shelled clams. Of greatest interest were the shelled cephalopods, destined to rapid development in Permian times (see Fig. 347).

On the bottoms of the Pennsylvanian seas lived great quantities of fusulinids, warm-water animals that made small spindle-shaped bodies of carbonate of lime (Pl. 16, Figs. 1, 2). These at times built up thick limestones, and were common even in Spitzbergen above 76° north latitude.

Foraminifera. — *Fusulina* is a genus of Foraminifera, the latter being one of the most primitive groups of the class Protozoa. Their shells are perforated by

openings or foramina, hence the name. Each foraminifer is a tiny globule of protoplasm with a central body known as the nucleus, which is the seat of vital energy. Some Foraminifera live in a single cell, but more commonly many cells are combined into a colony, as are the species of *Fusulina*. They are common as fossils since the Middle Cambrian but were not rock makers until the later Mississippian. Studied under the microscope, they are coming to be used in the determination of oil-bearing horizons.

CHAPTER XXXI

PERMIAN TIME AND ITS GLACIAL CLIMATE

When Sir Roderick Murchison had become widely known as the great leader in English Stratigraphy, he was asked by the Czar to study the geologic sequence of western Russia and chiefly of the Ural Mountains. In this work he was associated with Von Keyserling of Russia and De Verneuil of France. Their studies led to the discernment of a distinct series of highly fossiliferous marine and brackish-water formations that lay above the Coal Measures and beneath the Triassic. These were found well exposed along the western flank of the Urals in the Province of Perm, and using this geographic term Murchison proposed in 1841 to include them under his new term *Permian system*, which has now come into universal use.

The Permian is the closing period of the Paleozoic era, but in our continent the marine record stops with the Lower Permian, and there is no record of Middle and Upper Permian times other than that of erosion. Almost all of the Lower Permian formations occur in the Central Interior and southern Cordilleran regions of the United States. The marine waters that laid down these deposits came from the Gulf of Mexico; they were normally marine toward the south and west, but their northern and eastern extensions spread vast sheets of red beds that have thick deposits of anhydrite and salt. It was an epeiric sea surrounded by desert conditions, and the brackish-water phase entombed in places a wonderful series of reptiles and amphibians.

By far the best known sequence of American Permian formations is that of Texas, where they appear to continue the Pennsylvanian strata without a break. In the central and northern part of the state they are of the red beds phase, and as such are continued north across central Oklahoma and Kansas into eastern Nebraska. Here these deposits are not thick and are of brackish-water origin, thickening more and more into Oklahoma and Texas, where toward El Paso occur nearly 10,000 feet of dolomites, limestones and red beds, with vast amounts of anhydrite. In Texas the clastic materials appear to have been derived from the rising Ancestral Rocky Mountains in Colorado and New Mexico; they are vast tidal flat and river

Plate 17. — Late Lower Permian paleophysiography.

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 15, Map 4, for early Permian paleogeography.

The time of the seas shown on this map (the earlier invasions are in darker shading) is late Lower Permian, but the rising of the mountains came later. Eastern North America, in the Appalachian area, stood higher then than at any subsequent time. Note also the Ancestral Rocky Mountains of Colorado, and the several domal areas in the central United States (see pp. 553, 563). The medial ridge through the Canadian Shield is drawn too prominently, and epeiric seas may also have extended across the broken-lined area in California-Sonora.

The climate was warm arid, and the seas of the Great Plains area left much salt and gypsum in their withdrawal (pp. 561, 563). The Permian ice age came just after the time of this map and probably before the Appalachian Mountains had been completed (pp. 565–566).

deposits of an arid climate, spread eastward into the epeiric seas that came over the continent from the far south (see Pl. 17).

Salt Beds. — In the preceding paragraph attention was directed to the red beds of different ages and of vast extent in the southern medial region of this country. Such widely spread red formations indicate the presence of arid or desert climate, and their evidence is strengthened by that of the great salt beds of Texas, Oklahoma and Kansas. In the last named state, at Hutchison and Lyons, salt has been mined for some years, and the deposits are known to have a thickness of between 200 and 400 feet in an area of at least 7000 square miles. The time of the making of these salt beds was early Permian (upper Marion), and their greater extension is at least 100,000 square miles, making the largest salt area of the world. In

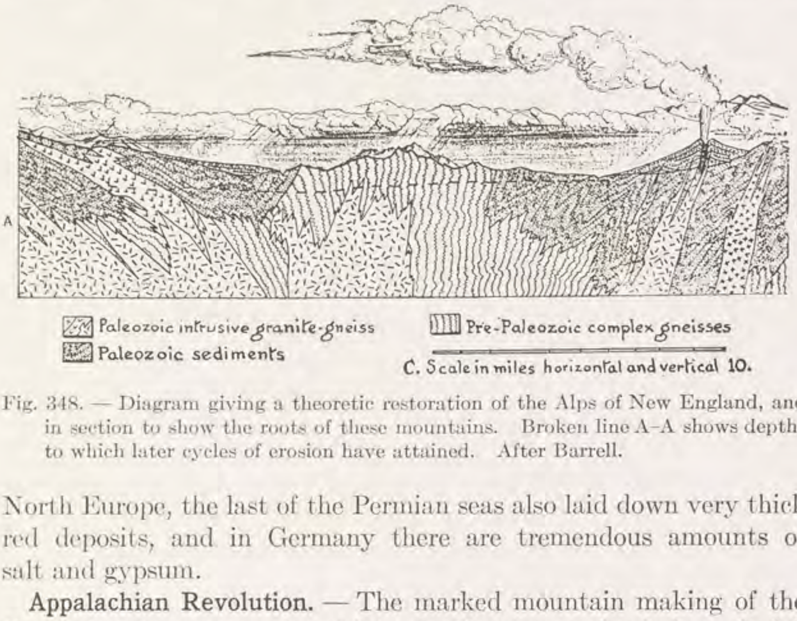

Fig. 348. — Diagram giving a theoretic restoration of the Alps of New England, and in section to show the roots of these mountains. Broken line A–A shows depths to which later cycles of erosion have attained. After Barrell.

North Europe, the last of the Permian seas also laid down very thick red deposits, and in Germany there are tremendous amounts of salt and gypsum.

Appalachian Revolution. — The marked mountain making of the Pennsylvanian was continued into the Permian, and culminated with the making of the Appalachians, the Ouachitas, and the Ancestral Rocky Mountains. Early in Permian times the whole of the Appalachian and Llanorian regions were again in the throes of mountain making, and with these uplifts, constituting the Appalachian Revolution, the epeiric seas of early Permian time all vanished from the continent. The northeastern half of the Appalachian Mountains was then most decidedly in motion. The extent of deformation was also greater than at any other time, since the Appalachians extend

from beyond Newfoundland to southern Alabama — a distance of over 2000 miles — while other mountains continue for 1200 miles southwestward across Texas, Chihuahua and Sonora. At the same time, all of the domes and axes of the eastern United States were accentuated. Finally, North America was completely emergent and greater than it is now.

The crustal instability of Europe during Pennsylvanian and Permian times appears to have been as marked as that of North America. The Alps of central Europe were reëlevated during earlier Permian time and toward the close of the period the Urals of Russia

Fig. 349. — Paleogeography and areas of known glaciation of early Permian time. Oceans are ruled, epeiric seas dotted, and places of glaciation lined (vertical lines, areas of proved glaciation; horizontal lines, of uncertain glaciation). Note the transverse shape and connected condition of the continents of this time.

were rising. From northern India east to China, mountains had also arisen in late Pennsylvanian times.

The Appalachian Revolution, beginning in Pennsylvanian and culminating in Permian time, was one of the most critical periods for the organic world in the earth's history, and may have been the greatest of them all with respect to changing environments.

Gondwana and Tethys. — There is much evidence of a geologic, paleontologic and zoölogic character, relating especially to the distribution of plants and animals since the late Paleozoic, which tends to show that Brazil was once widely connected with northwestern

Africa across what is now the deep Atlantic Ocean. This lost continent, known as greater Gondwana, was a vast transverse land stretching from the northern half of South America across the Atlantic to Africa and thence across the Indian Ocean to peninsular India (see Fig. 349). It was in existence throughout the Paleozoic. One of the chief lines of evidence for it is the occurrence throughout the southern hemisphere of the Permian deposits having the Gangamopteris flora (see p. 566), the seeds of which paleobotanists hold could have been so widely distributed only across a continuous land.

Glacial Climate. — For nearly fifty years geologists have been describing unmistakable glacial deposits of Permian age in the continents of the southern hemisphere, but it is only during the present century that their results have been widely accepted. It is now known that glacial deposits — glacial clays called tillites — are of wide distribution.

All of Africa and Madagascar south of 22° and 23°, respectively, was covered by ice sheets that at their maximum were between 4000 and 5000 feet thick. The Transvaal sheet was the most extensive, moving at least 700 miles to the southwest. Eight or nine horizons of glacial rock débris derived from floating icebergs occur in South Australia above the Coal Measures, some of them 200 feet thick, interbedded in 2000 feet of marine strata, and in India the very thick glacial deposits (Talchir) preceded the Permian submergence. The old polished, striated, and grooved ground over which the glaciers moved is known in India, Africa and Australia. In North America, tillites seemingly of Permian age are known about Boston, Massachusetts, and striated stones have been reported on Prince Edward Island; tillites are also known to occur in different places in Alaska. For the complete distribution of these glacial deposits, see Fig. 349.

The Permian glacial formations occur mainly on either side of the equator from about 20° to 35° north and south latitudes, but evidence of this kind is scattering above 35° in north temperate lands. The evidence is now unmistakable that toward the close of the Lower Permian, most of the lands of the southern hemisphere were under the influence of a glacial climate as severe as the polar one of recent times, and that, like the latter, the Permian one also had warmer interglacial periods, for coal beds occur associated with the glacial deposits in Australia, South Africa and Brazil.

What brought about this great change in the climate of Permian time, and why it was, apparently, mainly restricted to the southern hemisphere are as yet unsolved problems. Most geologists look

for the explanation in the great derangements of the air and oceanic currents brought about by the marked crustal unrest during Pennsylvanian and Permian times.

Life of the Permian

The glacial climate and the subsequent long-continued arid conditions in the Permian wrought a mighty change in the life, both of the lands and oceans. With the increased cold, there came into existence in the southern hemisphere a hardier flora, known as the *Glossopteris* or *Gangamopteris flora*, because of the prominence in it of these two plants (see Fig. 350). This flora, with its greater abundance of seed plants, appearing at about the same time in Africa, Australia, Tasmania, southern India and South America, provided a different, and probably a better, food for the reptiles of the land, and accordingly we see a marked evolution among them. These land vertebrates, remains of which occur in the red beds of eastern New Mexico, central Oklahoma, and especially in northern Texas, are discussed further in the next chapter. Their higher development is held by some authorities to be the most important phase of the whole progress of evolution, for by the close of the Permian we find forms foreshadowing the chief groups of the higher vertebrates of modern times.

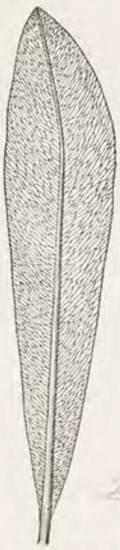

Fig. 350.—Leaf of the Permian net-veined seed-bearing *Glossopteris* (*G. indica*). From Credner's *Elemente der Geologie*.

During the Lower Permian a great change also took place among the insects, for they became not only smaller but more like modern forms (see Fig. 351). Judging from the insects of Triassic times, we see that those of the later Permian must have introduced complete "metamorphosis" (a transformation, as maggot to fly, or caterpillar to butterfly) and resting stages, as a result of the winters and seasons of drought.

In the seas there was a great dying out of many kinds of corals, brachiopods and trilobites, their places being taken by the ammonites of the cephalopod group, lobsters (first appearing as fossils in the Middle Triassic), and modern molluscs and corals. Just as the river fishes of Devonian time had peopled the seas, so now the land

reptiles began to return to this habitat (*Mesosaurus*), and this early adaptation is a prophecy of the many kinds of marine reptiles that were to flourish in Mesozoic time.

The last stand of the known Paleozoic marine life was in extensive Tethys, the greater Mediterranean, whose rock and organic records

Fig. 351. — A primitive insect (*Dunbaria fasciipennis*) from the early Permian of Kansas, preserving the color pattern. × 2.5. Original at Yale University.

are found in the eastern Alps and the lands to the east as far as the Himalayas. In these warm shallow waters of late Permian times the descendants of the Upper Carboniferous corals, brachiopods and molluscs still swarmed in varied profusion. When the record of the marine Triassic begins, however, it shows that a great change has taken place, for now nearly all the Paleozoic forms are gone.

CHAPTER XXXII

THE COMING OF LAND LIFE

All animal life is, in the last analysis, dependent upon plants for its existence, and without land plants it would have been impossible for the fishes of the rivers to spread their descendants over the lands as the higher vertebrates. Hence, before we can study this very significant evolution, we must see how the lands came to be covered with vegetation.

The Rise of Land Plants

Plants of some kinds now live in all lands up to the highest altitudes and even in the driest of deserts. This, however, has not always been so, since we have seen that no land plants are known in the Cambrian and older strata. Land floras, or plant assemblages, first appear with the Devonian, and in the Pennsylvanian there is revealed to us a most wonderful primitive vegetation, making it possible not only for snails, but as well for some water-living arthropods, to adapt themselves to the dry land and become changed into insects, thousand-legs and spiders. This migration of animals from their original water homes to terrestrial ones began with the scorpions, as we have seen, at least as early as the Silurian, followed shortly afterward in the Devonian by the amphibians.

The known land plants of Silurian time are as yet exceedingly few and the specimens rather indistinct. With the Lower Devonian we get the first well known forms (*Rhynia* and *Hornea*), very primitive types, but little more advanced structurally than the seaweeds. In the Middle Devonian, plants are present in enough abundance and variety for us to speak of floras, and from that time on they advance steadily in numbers and diversification. Our concern in this chapter, however, is chiefly with the floras of the Pennsylvanian, partly because of their significance in the making of the Coal Measures, but more particularly because of their part in making possible the evolution of the higher vertebrates.

Pennsylvanian Floras. — The coal floras, from which upward of three thousand species have been described, are conspicuous for their almost world-wide distribution and their luxuriance and abundance. Their most striking representatives in number and size were the

scale trees, a sort of evergreen unlike anything living. Another remarkable group were the gigantic calamites, living segregated like the modern cane brakes and bamboo thickets. The floras also included many fern-like forms, both delicate and hardy, some of which were climbing in habit, while others grew into majestic tree-ferns (Fig. 346).

Shades of green were the dominant color, and the monotone of the verdure was nowhere enlivened by bright flowers. Flowers were present, however, but of a low order, insignificant in size and doubtless unattractive. Probably more than one-half of the flora was spore-bearing (see below) and we may safely regard most of the more common plants of the Coal Measures as seedless. Fertilization was not yet accomplished through the aid of honey- and pollen-eating insects as is so general among the living flowering plants of the present, but was brought about by the rains and winds. Among these floras the following groups were the most conspicuous.

Spore-bearing Flowerless Plants. — The more primitive type of plants differed from the later ones in reproducing by spores instead of seeds. Spores differ from seeds in that while both give rise to sexed plants, in the case of the latter these sexed plants again produce seeds directly, while the sexed plants of the former are short-lived and give rise to sexless, long-lived plants that in turn bear the spores. In other words, the spore plants are said to have an "alternation of generations," while the seed plants have direct development.

Among the spore-bearing plants, primitive ferns are not common as fossils until the Pennsylvanian, when many species of the smaller herbaceous kinds occur, associated with the tree-ferns, some of which attained a height of 50 feet. It was these ferns that gave rise to the later seed-bearing kinds.

Among living plants there is a small group of forms having a very wide distribution and popularly known as rushes. As a rule they are small plants, less than 18 inches tall. The Pennsylvanian floras had a great variety of ancient rushes, the largest of which are called calamites (see Fig. 346). They were prolific plants and sometimes attained a diameter of 12 inches and a length of more than 30 feet. In them the wood cylinder was far thicker than in living rushes.

Still a third group are the lycopods, very widely distributed, primitive, herb-like, evergreen plants known as ground pines and club mosses. In the Paleozoic, similar forms were the dominant plants, but reached gigantic proportions; they are known as scale and seal trees because of their scale-like appearance, due to the leaf-bases on the trunks and branches (see Figs. 341, 346).

Seed-bearing Plants. — Restricted to the Paleozoic are many plants having all the appearance of being true ferns, but bearing seeds instead of spores (see Fig. 346). These are the pteridosperms. Their development of flower into seed was a great forward step in the evolution of the plant world, and became the dominant feature of later floras.

Other Paleozoic seed plants were the cordaites, trees not unlike modern pines or conifers. They did not live in swamps, as did the previously mentioned groups, but on the higher ground. Out of the cordaites came the modern pines.

The Rise of Land Vertebrates

Fishes. — The fishes probably arose in fish-like ancestors, possibly the gilled lancelets sometimes spoken of as "the prophecy of a fish." These in turn may have originated in some of the marine annelids. The lancelets of the ancient seas are thought to have spread into the rivers after they had become peopled with water-living plants, and, feeding upon these, to have gradually developed into tiny sharks, the acanthodians. But the rivers are continuous habitats only in wet climates, and in semiarid regions they often dry away, and so destroy all of their life. In such evanescent waters the acanthodians are believed to have learned how to tide over the dry seasons by hibernating in wet sands and gulping in air. We will return to this subject later in the chapter.

Fishes are back-boned animals, the first markedly successful class of vertebrates. They are as well adapted to the water as the birds are to the air. Their body temperature is about that of the water in which they live, wherefore they are said to be cold-blooded, and they have gills on each side of the head for oxygenating the blood. Their principal organ of locomotion is the powerful tail fin. This is assisted by paired fins, of which the forward pair are known as the pectoral fins and the rear ones as the pelvic fins. It is out of these fins, or limbs, that the fore and hind legs of the higher vertebrates arise. An air-bladder is generally present; this may serve as a float, but in certain forms has been modified into a cellular sac which acts as a lung and assists the gills in respiration. As will be shown later, it is this cellular sac that has the possibility of modification into lungs in the amphibians.

The oldest known "vertebrates" are the small "winged fishes" (ostracoderms) (see Pl. 13, Figs. 1, 2), beginning in the Champlainian and vanishing with the Devonian. What their relationship was to

the true fishes is unknown. Externally they were bony-skinned, and they were devoid of paired fins, since the anterior " wings " are not believed to be the homologues of the anterior pair of fins in true fishes.

Unmistakable fishes are the gristle fishes or sharks (elasmobranchs), and of these the oldest and most primitive are the small spinous forms (acanthodians) appearing in the Silurian and vanishing with the Permian (Pl. 13, Fig. 3). Out of them probably arose the ganoids of Devonian time, fishes whose scales were thick and bony and covered with bright enamel. This stock, remaining continuously in the water, gave rise to the dominant bony fishes of to-day. Out of its more primitive branch, however, the air-breathing Crossopterygii, came the primitive transition animals developing into amphibians through changing the air bladder into lungs and the paired fins into limbs (see below). All of this took place before the Upper Devonian, since in this epoch there is evidence that primitive amphibians were already present (*Thinopus*, see Fig. 340).

Evolution of Lungs. — In order to be able to live out of water, and so survive periods of drought, it became necessary for the fishes to develop a means of breathing air, since their normal breathing organs, the gills, are adapted for extracting oxygen from the water but not for taking it directly from the atmosphere. This they did by a modification of the air bladder from a hydrostatic organ into a lung. The great range of modification of the air bladder shows it to be of extremely ancient origin, and its incipient condition is possibly shown by a pair of pouch-like out-growths of the pharynx, or throat cavity, in the sharks. Stagnation of the water and a loss of the free oxygen would bring the fishes to the surface to gulp down air, and such pouches, if supplied with blood-vessels, would serve in a very rudimentary way to aid in aërating the blood. A premium placed by the environment upon such structures would, it is thought, stimulate their development to the condition seen in the modern lung-fishes.

Animals living in permanent bodies of water have no need to breathe the air, and it is, therefore, held that the stimulus for such an alteration could have arisen only where the water periodically failed the animals. Just as we have arid regions to-day, so similar land climates existed during all of geologic time. Under such climates, bodies of water come and go according to the season of rain and drought, and hence various methods are resorted to by the animals to maintain their kind or themselves over the period of drought. During the arid season the struggle for existence is severe,

not only because of the abnormal crowding of the individuals into constantly diminishing spaces and the reduction in the amount of available food, but even more so because of the increasingly saline and bitter character of the water. It is thought that under the stimulus of these changes, gill-breathing fishes first adapted themselves to burrowing in the sand. Thus protected in water and mud holes, there was for a time moisture to pass over the gills, but under such environments life was very precarious and in the struggle most of the individuals were destroyed. After innumerable failures in their efforts to gulp the air into the pharynx, efforts lasting through long geologic time, the ganoids and lung-fishes were gradually developed and perfected, their first appearance being in earliest Devonian time.

Amphibians. — As we have seen, the first air-breathing vertebrates came out on the dry land as early as the early Devonian. They were, however, still more or less addicted to water habitats, and their living representatives have never learned to lead an active life on the dry land. Despite their newly acquired ability to breathe air and even to hobble about on land in search of new water holes, it was only in the waters that they could lay their eggs and successfully rear their young. This dual mode of living led to the evolution of the next highest group, the Amphibia, as we may see reflected in the development of living frogs, whose eggs develop into little, fish-like, gill-breathing polliwogs that gradually change into lung-breathing, four-legged adults (see Fig. 352).

Frogs, newts, sirens, mud-puppies and land salamanders are types of living amphibians (Pl. 18). They are all cold-blooded, like the fishes. The class name Amphibia means *living a double life*, and has reference to their habit of living both on the land and in the fresh waters. Some of them, however, live entirely in the water, and, as a rule, all amphibians in their younger stages are wholly restricted to this element.

All Amphibia in their youth are provided with two or three pairs of external gills or internal ones with external gill-clefts, soft feathery outgrowths situated at the back part of the head and rich in blood-vessels (see Pl. 18, Fig. 2). Such gills are also present in the lung-fishes, and in the sirens and mud-puppies they may persist throughout life, though this condition is rather exceptional. In the salamanders of the land, and in all of the tailless Amphibia (frogs, etc.), the gills disappear and adult respiration is carried on wholly by lungs, as in the higher vertebrates.

The first vertebrates having legs with toes appeared in the De-

vonian. They are known as Stegocephalia (see Pl. 18, Fig. 4, and Text Fig. 346), a name which has reference to their covered or armored head; this head covering was inherited from their fish forebears, and it at once distinguishes the Paleozoic and Triassic amphibians from all living ones. It was in turn transmitted to the most primitive reptiles, the Cotylosauria (see p. 575).

In all well preserved Stegocephalia, the skulls were pierced not only by the large lateral orbits in which the paired eyes were situated, and by the pair of anterior nasal openings, but also by a single small orifice through the bone over the brain. This aperture is of great interest, for in it was situated a third eye known as the *pineal eye.*

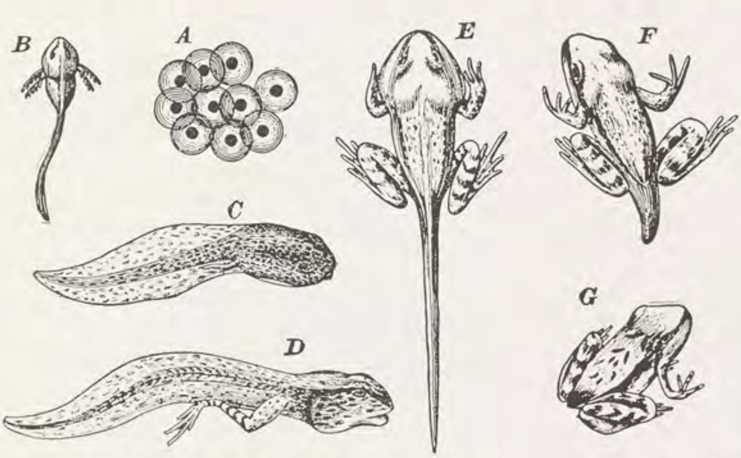

Fig. 352. — Development of the frog (*Rana temporaria*). *A*, eggs, greatly enlarged; *B*, tadpole or polliwog, with two pairs of gills; *C*, tadpole with first indication of hind legs; *D*, older tadpole; *E*, tadpole with both pairs of legs free; *F*, *G*, stages in which the tail is resorbed. Redrawn from Leuckart's wall charts.

Such an opening is also found in many fossil and some living reptiles (*Sphenodon*), and the organ it contains is a vestigial one whose ancestry can be traced back at least to Pennsylvanian time. The rudiments of this eye are present in the brain of all living vertebrates, including man.

The amphibian fauna of the coal swamps of the Pennsylvanian was a highly varied group of land animals, ranging in size from less than 2 inches in length to as large as an adult Florida alligator. Most of them, however, were small creatures related to the living salamanders, but, being more primitive, are known as branchiosaurs and microsaurs (Fig. 346). They were rather sluggish animals, living about or in the water.

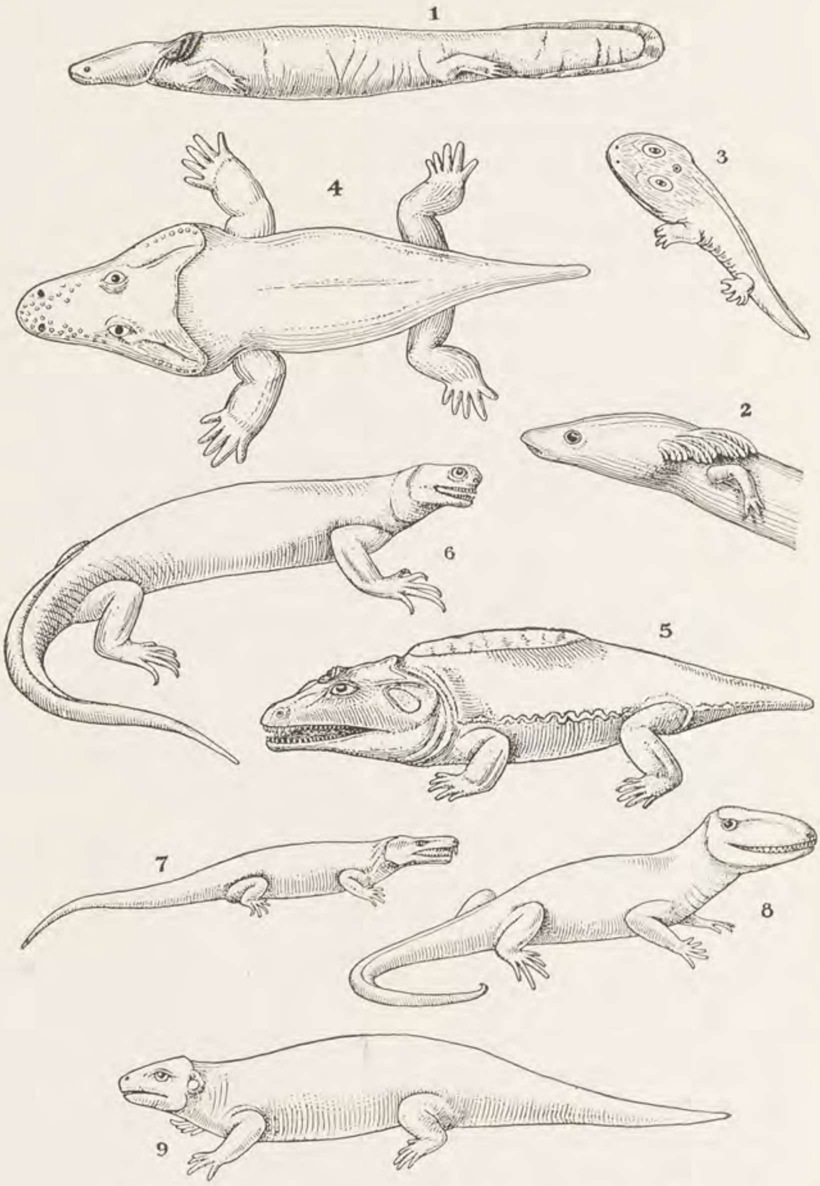

Plate 18. — Living (1, 2) and Permian amphibians (4, 5), and Permian reptiles (6–9).

Fig. 1, mud-puppy, *Necturus maculatus;* 2, salamander, *Siren lacertina;* 3, tadpole-like stegocephalian, *Branchiosaurus;* 4, stegocephalian, *Trematops milleri;* 5, *Cacops aspidephorus;* 6, *Casea broilii;* 7, *Limnoscelis paludis;* 8, *Ophiacodon mirus;* 9, *Diasparactus zenos.*

Reptiles. — In all of the vertebrates so far studied — fishes and amphibians — we have seen that the habitat is either wholly in the water, or that at the very least the small eggs are there laid and fertilized, and that the young are also born and spend the days of their youth in this element. All of the higher vertebrates remove themselves more and more from this habitat, and none are developed in it directly from the egg. In other words, the reptiles, as a rule, are oviparous, laying large eggs like those of birds and provided with a more or less great quantity of food (yolk), and these eggs are fertilized before they are laid upon the land, where they hatch under the warmth of the sun. This is the most important and fundamental difference between the lower vertebrates, the fishes and amphibians, on the one hand, and the higher vertebrates, the reptiles, birds and mammals, on the other.

All of the living animals known as turtles and tortoises, lizards and snakes, alligators and crocodiles, belong to the class Reptilia. The word reptile means *creeping* or *crawling*, and has reference to an animal that goes on its belly like the snake, or moves with difficulty on short sprawling legs, like the alligator. There are, however, many reptiles that are in no sense creeping and crawling animals, as, for instance, many of the fleet-footed lizards, certain of the medieval dinosaurs with their pillar-like legs, and the winged pterodactyls.

All living reptiles are cold-blooded animals like the two lower classes of vertebrates, and their skin is never soft but always more or less hardened by horny or bony material that occurs more often as scales than as armor plate. Each animal has a pair of lungs, but in the elongated snakes the left lung is rudimentary and almost lost.

In the snakes and in some lizards, legs are either wholly absent or mere vestiges buried in the flesh.

Most of the Pennsylvanian and early Permian reptiles were plump, sluggish, more or less sprawling animals, basking often on the land in the hot sun. In many ways they still resembled the stegocephalians, their associates, but had a marked tendency toward a reduction in the size of the skull and toward loss of body armor. In all the forms the feet terminated in five fingers or toes, and few appear to have been swift of foot.

The most primitive reptiles are the Cotylosauria (Pl. 18, Fig. 7). This order, as seen in *Limnoscelis*, may well have been the central stock out of which evolved directly or indirectly the lizards, alligators and dinosaurs.

In the Permian and Triassic of Africa and North America are found reptiles of the order Theriodontia (meaning *wild beast*), so named because the teeth are of the carnivorous type. They were active and lizard-like, ranging in size from small forms to those as

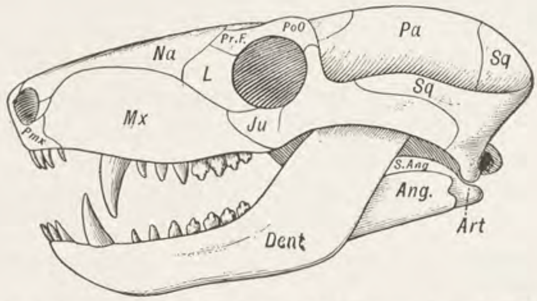

Fig. 353. — A theriodont reptile skull, about 4 inches long, from the Triassic of South Africa, showing primitive mammalian type of teeth. After Broom.

large as a tiger. They are of great interest because the African forms are regarded as having given rise to the lowest or egg-laying mammals, while in the American forms originated the higher reptiles. Their teeth were differentiated and localized, as in mammals, into incisors, canines and molars (see Fig. 353).

CHAPTER XXXIII

THE BEGINNING OF MESOZOIC TIME: THE TRIASSIC PERIOD

To the founders of Geology the Mesozoic rocks were known as the " Secondary " formations, situated above their Primary (Paleozoic and older eras) and beneath their Tertiary (Cenozoic). To them, the Mesozoic was, therefore, the middle or medieval time of the earth's history, and they selected a name meaning medieval life to express that idea. It is now well known that the Mesozoic formations are far from holding the middle *time* of geologic history, but the *life* known to geologists is medieval in character and it is in this sense that the term is used.

The Mesozoic era, though of very long duration, was only one half as long as the Paleozoic, or even less, but it was twice as long as the Cenozoic. It is divided into three periods; the Triassic, so-called from its threefold development in Germany and the Alps; the Jurassic, named from the Jura Mountains; and the Chalk or Cretaceous.

The Mesozoic has long been called the " Age of Reptiles," because its dominant animals belonged to that class; " they filled all the rôles now taken by birds and mammals, they covered the land with gigantic herbivorous and carnivorous forms, they swarmed in the sea, and, as literal dragons, they dominated the air " (Scott). The mentality of the Mesozoic Reptilia was always of a low order, but out of them in the Triassic arose the small reptilian and egg-laying mammals, and from another stock came the reptilian birds.

Among the marine invertebrates, none were more significant of Mesozoic time than the cephalopod group known as the ammonites, to be further described in the Jurassic chapter. The forms living in the Permian gave rise to a wonderful evolution in the Triassic, but were almost exterminated at the close of this period; another rapid evolution took place in the Jurassic, with the Lower Cretaceous they began to show decline, and before the close of the Mesozoic they had disappeared.

The floras had also undergone great changes, since all of the more significant spore-bearing plants of the Paleozoic were practically gone. The older seed-bearing plants had given rise to a medieval

flora composed of conifers, maidenhair trees (gingkos) and cycads in greatest variety. With the Lower Cretaceous there rose into ascendency the modern flowering plants, and with them the modern insects (beetles, flies, butterflies, bees, wasps).

The Triassic Period

Probably the most striking thing about the North American Triassic, and the Jurassic as well, was the emergent condition of the continent. The only flooding by the oceans was along the western part of North America by the Pacific, and in Mexico by the Gulf. Because of this emergent condition, desert climates prevailed, and the geologic record, therefore, consists largely of coarse, red, fresh-water deposits, with scattering fossil plants and bones of reptiles. Along the Pacific side of the continent, however, there are wide-spread marine formations with coral-reef limestones. In these marine deposits, which are usually very thick, there are vast amounts of volcanic ash and lavas, attesting to an abundance of volcanoes from California far into Alaska. Lavas also flowed widely in the fault-troughs of eastern North America from Nova Scotia to Virginia.

The Triassic of North America is thus displayed under four different regional sedimentary and faunal phases: (1) Atlantic border intermontane continental, (2) western Cordilleran desert and fresh-water, (3) Mexico marine, and (4) Pacific coast marine, which we shall study in the order named.

Atlantic Border. — The term Newark, taken from the city of that name in northern New Jersey, has been given to the red sandstones found upon the Piedmont Plateau. Beginning with about Middle Triassic time, the several regions of Newark sedimentation — Nova Scotia, Connecticut, and New Jersey to North Carolina — began to fault along one side, and certain narrow but long areas began to subside as troughs, while the adjacent spaces stood firm as unmoved blocks, or actually rose. In this way the median arch and the lateral highlands were reëlevated from time to time, and their eroded material was moved by the rains and wind into the subsiding valleys. Such major fault lines occur along the eastern side of the Connecticut valley (here the final displacement was about 2 miles), and others are known in the western parts of the Triassic areas of Maryland, New Jersey and Pennsylvania, and in Nova Scotia as well. In this way the constantly rejuvenated highlands were subjected to quick erosion, and into the sinking valleys on the sides of the highlands the aggrading waters brought down vast amounts of sediment, the

present Triassic formations. In the Connecticut valley there are from 10,000 to 13,000 feet of continental deposits (Fig. 354), in New Jersey and in southeastern Pennsylvania the maximum thickness is said to be over 20,000 feet. Southward these deposits thin rapidly, and to the west of Richmond, Virginia, they are about 2500 feet thick, with 3000 feet in North Carolina.

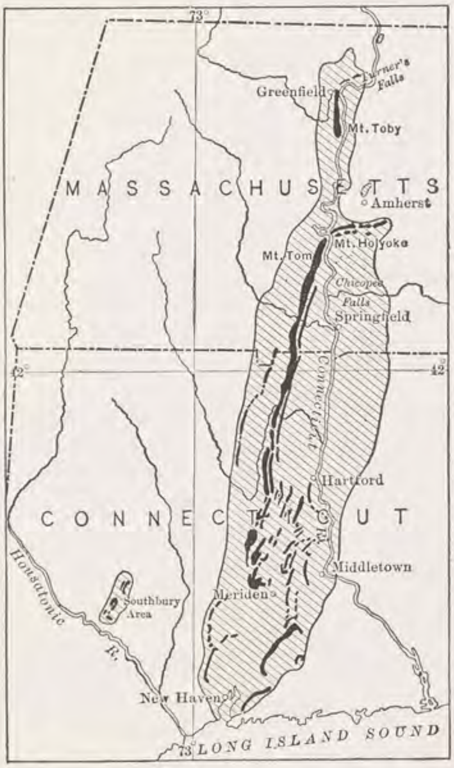

Fig. 354. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Connecticut valley. U. S. Geol. Surv.

From northern Virginia to Nova Scotia the Newark sandstones and mudstones are prevailingly red in color and consist almost throughout of conglomerates, sandstones and shales. All of the material is poorly washed or assorted, and in most places is a heterogeneous mass of detritals, with the greater part of the conglomerates and coarser sandstones situated near the fault scarps whence they came. The sediments are much cross-bedded, abundantly sun-cracked, rain-pitted (Fig. 358), and rippled, with the feldspars undecomposed; they are the erosion material of a high land of crystalline rocks, deposited in a semiarid desert with hot summers and possibly cold winters. The bulk of the material is from igneous and metamorphic formations of eastern Appalachis.

In the Upper Triassic areas of Virginia and North Carolina there is much black slate with decidedly local bituminous or humic coals, and rarely a zone of black-band iron-ore. The coal beds vary in thickness from a few feet to 13 and even 26 feet. Plants are common here. These dark deposits with coal swamps show that the climate was not always and everywhere semiarid, but that locally there were humid climates, with swamps.

Nowhere have the Newark strata yielded a single marine fossil, all of the recovered organisms being those of the land (plants and vertebrates) and of fresh waters (fishes, bivalves). Actual remains of plants and animals are always rare in red desert deposits, and the common organic evidence, therefore, consists here of footprints made chiefly by dinosaurs (see Fig. 358).

In all of the Newark areas from Nova Scotia to North Carolina are found igneous rocks that in the lower strata occur as intruded sheets and dikes of trap (diabase), and higher up are extruded sheets of basaltic lavas in thicknesses up to 900 feet (Fig. 354). These are seen to best advantage along the Hudson River of New Jersey, where they make the well known Palisades, whose vertical walls of columnar rock exhibit the edge of a great intruded sheet of diabase. The molten material welled up repeatedly toward the close of Newark time through fissures situated in the deepest parts of the subsiding areas and near the great faults.

Palisade Disturbance. — At the close of the deposition of the Newark series, crustal deformation again set in, apparently on a considerable scale, from Nova Scotia to South Carolina, and this makes a natural boundary between the Triassic and Jurassic. Everywhere this new area of deformation lay east of the Appalachian foldings, whose trends the Palisade Mountains nevertheless closely followed. The former mountains had been folded and overthrust to the west, but now the surface was elevated and torn apart, resulting in numberless fractures and faults (tensional) of varying magnitude, and moving the strata in each basin into a series of monoclinal blocks, that is, all tilted in the same direction. As a result there were formed chains of block mountains, the Palisade mountains of Dana; this deformation has been called the Palisade Disturbance.

Cordilleran Region. — A second area of Triassic fresh-water deposits lies in the Cordilleran region. Throughout the Rocky Mountains south of the Canadian border, but more especially from Wyoming into western Texas, and in northern New Mexico and Arizona, occurs a series of red or variegated sandy shales and cross-bedded sandstones, with zones of gypsum sometimes 40 feet thick, that lie over the eroded surfaces of the older formations, and commonly on similar red beds of Permian or Pennsylvanian age. Over a large part of the area the basal conglomerate (Shinarump), is the preserved floor of a desert. These Triassic formations belong to the later portion of the period.

The fossils of these Upper Triassic red beds are scanty indeed, although in many places occur bones of amphibia (Stegocephalia),

but mainly of reptiles of the ancient crocodile type (*Mystriosuchus*, Fig. 355). Frequently is found drifted wood that is now agatized; in the Petrified Forest of Arizona, near Flagstaff, this is exceedingly common.

Mexico. — In central Mexico there is marine Triassic with fossils that show linkage with the Mediterranean. We will have more to say of this seaway in later chapters.

Pacific Border. — Coming now to the greatest development of marine Triassic in this country, it is evident that beginning in the late Paleozoic there developed out of the western portion of the

Fig. 355. — Restoration of the Upper Triassic crocodile-like reptile *Mystriosuchus*. The plants are rushes and cycads (upper left-hand corner). After Williston, from his *Water Reptiles*.

Cordilleric geosyncline a northwest and south-southeast trending trough, the Pacific geosyncline, which opened out into the Pacific across northern California and southern Oregon, and again in south-eastern Alaska. The southern portion of this trough was the *Californic sea,* which persisted all through the Mesozoic. To the west of the trough there lay a foreland, nearly all of which has since gone into the depths of the Pacific, leaving the Coast Range as its only remnant (see Pl. 19).

The sequence of Triassic formations and faunas of the Californic sea is unusually complete, and compares favorably with that of most

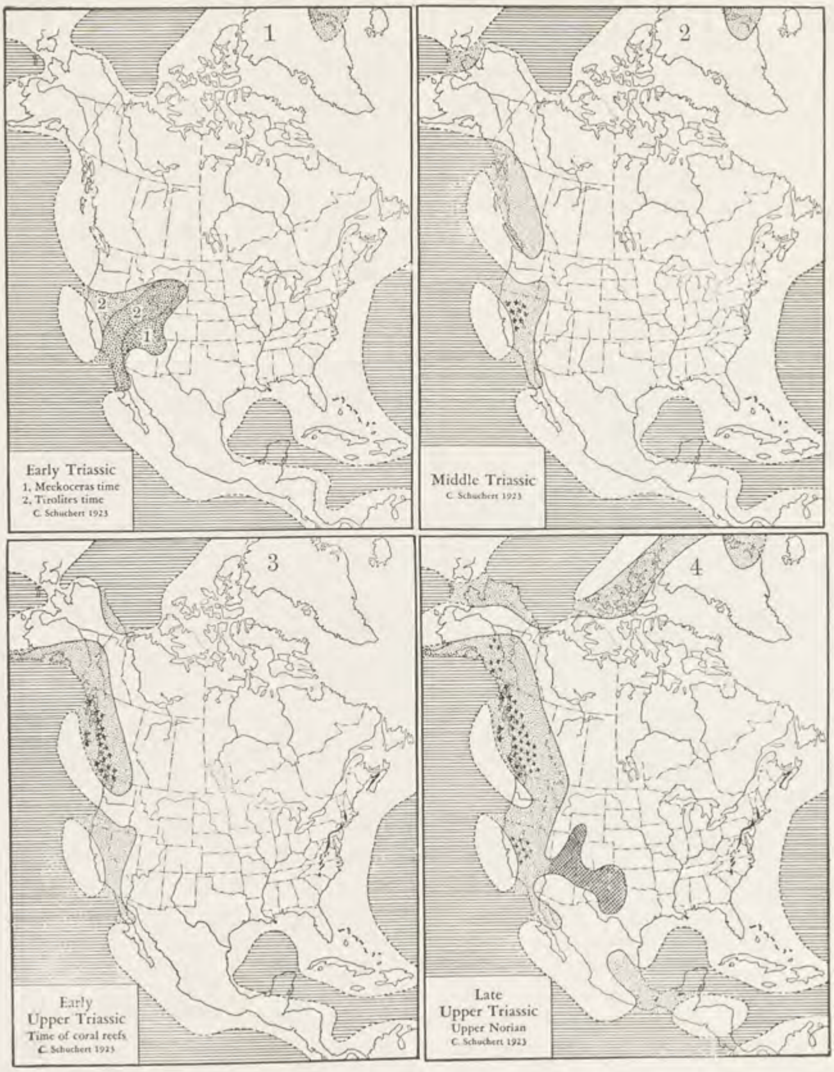

Plate 19. — Paleogeography of Triassic time.

Epeiric seas dotted; oceans ruled. Desert and semiarid deposits either cross-ruled or solid black (along Atlantic piedmont). Volcanic regions indicated by crosses.

Note the absence of the Appalachic geosyncline, and that the marine areas are in the Cordilleric and Mexican regions.

other regions of marine sedimentation; the deposits are usually calcareous and fairly thick (about 4000 feet). The normal marine waters in early Triassic time spread across California, Nevada and Oregon into Idaho and Utah, and possibly even into central Wyoming, but before Middle Triassic time this sea withdrew more and more to the westward.

In the Middle Triassic there also appeared a wide and long trough throughout British Columbia, which in Upper Triassic time extended far to the north into Alaska and south into Washington and Montana. This was the *British Columbic sea* of the Pacific geosyncline, persisting into late Cretaceous time.

Along the Pacific border of British Columbia, from Vancouver north to Alaska, the Upper Triassic alone is present, and it increases to very great thicknesses (13,000 feet). The significant feature here is that nine-tenths of the rocks are lavas and ashes, largely the material of submarine eruptions (see Pl. 19).

These western interbedded marine and volcanic deposits undoubtedly extended eastward to the Rocky Mountains, where Upper Triassic strata and faunas occur all the way from Alaska south into Washington. In the coastal mountains of British Columbia, they have been eroded away from above the granitic bathyliths that rose into high mountains beneath them toward the close of Jurassic time.

Life of the Triassic

The Triassic seas swarmed with ammonites in great variety, and some of the species spread widely throughout the world (Pl. 20). They were not only the most beautiful and characteristic animals of the Mesozoic seas, but also the highest expression of invertebrate evolution in agility and in predaceous and scavenging ability.

In the Upper Triassic appeared the modern reef-building corals (Hexacoralla), which built limestones in Tethys up to 4000 feet thick, while reefs are known elsewhere with many identical species, as in the Himalayas and in the eastern Pacific from California to Alaska. The modern echinids and lobsters also began to stand out at this time, but were not markedly conspicuous until later. Tethys and the Pacific were the main centers of marine invertebrate evolution.

Some of the early fresh-water vertebrates, as we have seen in previous chapters, were forced by stress climates to adapt themselves to the land, and attained this habitat only after a very long struggle. Now that the reptiles were firmly established on the land, however,

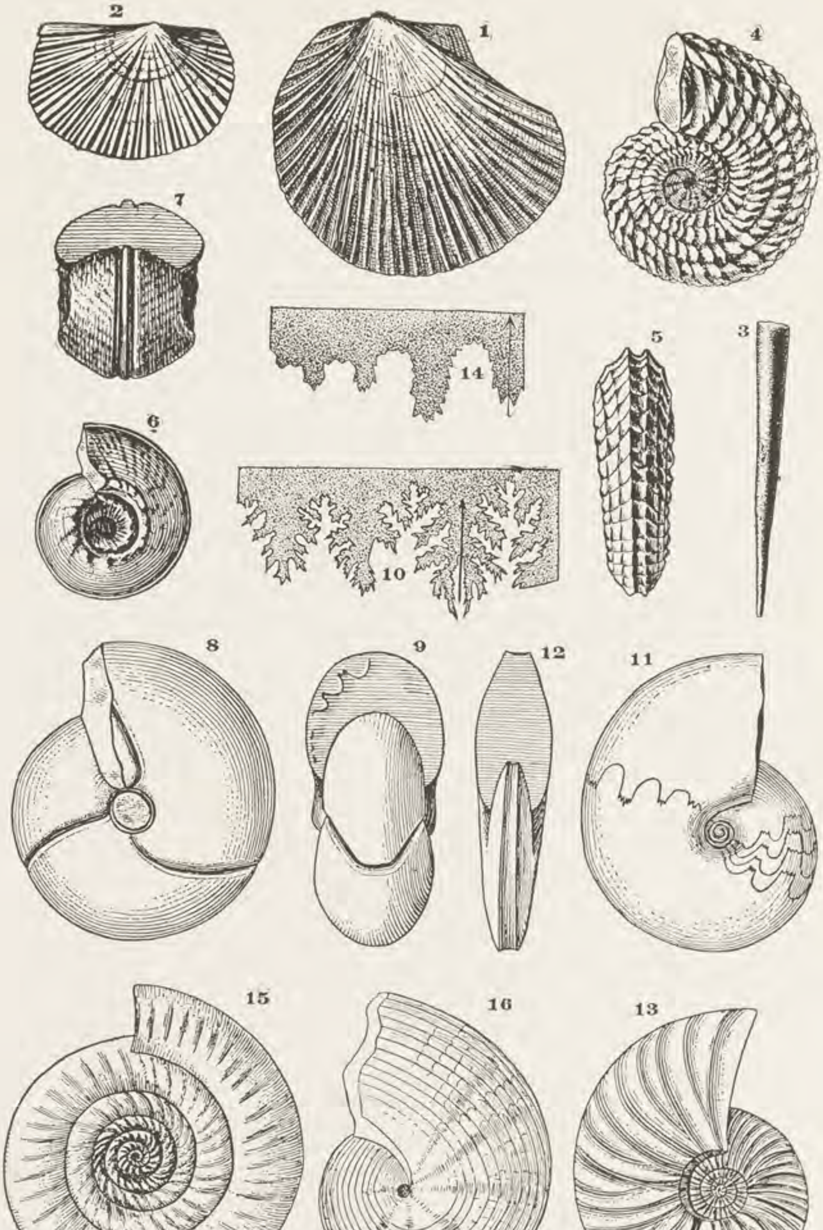

Plate 20. — Triassic bivalves (1, 2), belemnite (3), and ammonites (4–16).

Fig. 1, *Pseudomonotis subcircularis;* 2, *Daonella dubia;* 3, *Atractites burckhardti;* 4 and 5, *Anolcites meeki;* 6 and 7, *Tropites subbullatus;* 8–10, *Joannites nevadanus;* 11 and 12, *Meekoceras gracilitatis;* 13 and 14, *Gymnotoceras russelli;* 15, *Tropigastrites rothpletzi;* 16, *Sageceras gabbi.* After J. P. Smith, from the U. S. Geological Survey.

we see some stocks of them going back again to the water, not only intermittently to the rivers and lakes, but permanently into the seas and oceans, where there is always a more abundant animal food supply than is usually the case on the land. Dolphin-like reptiles, the ichthyosaurs, were abundant in the later Triassic, and long-necked, turtle-like reptiles, the plesiosaurs, also had their start at this time. More will be said of these groups in a later chapter. Here again we see the wonderful extent to which organisms can adapt themselves, for limbs have been changed from walking legs to swimming paddles, and the egg-laying method of rearing the young has been altered to that in which the young are born alive (viviparous development).

Fig. 356. — Giant broad-leaved Triassic fern, *Macrotæniopteris magnifolia*. U. S Geol. Surv.

The known Triassic floras are small, with the best representation in Virginia. Practically all the known plants are of Upper Triassic time. Of the Paleozoic genera, nearly all had disappeared, and we have in their stead rushes (see Fig. 355), many of them large, ferns (see Fig. 356), including tree-ferns, and cycads and conifers, in many genera whose representatives now live in tropical and subtropical regions. The evergreen trees were dominant in the forests and were as tall as the conifer woods of to-day.

In the modern warm-climate floras, the living cycads (Figs. 318, 355, 357) are the remainders of a once more diversified group. So dominant were they in the floras of the earlier half of the Mesozoic era that this time is also called the Age of Cycads.

The Triassic vertebrates of the land were very varied and of great interest, exhibiting much structural and adaptive progression over their late Paleozoic ancestors. Among the amphibia, the stegocephalians attained their culmination in number, variety and size. Progress was, however, especially marked among the Reptilia as a class, and specifically among the active dinosaurs. These strange reptiles, to be described in the next chapter, were the lords of the

Fig. 357. — Living cycads in the New York Botanical Garden in 1908. Plants of this kind were common in Triassic and Jurassic times.

Fig. 358. — Slab of Triassic sandstone, 6 by 3.5 feet, pitted by rain. A large dinosaur (*Steropoides diversus*) walked over the muddy ground before the shower, and a much smaller one (*Argoides minimus*) afterward. Peabody Museum, Yale University.

land, and they were present in great variety and in great size; in fact, some, known by their footprints alone, must have been larger than elephants (Fig. 358). By the Upper Triassic they had become adapted to all the land habitats.

Fig. 359. — Lower jaws of reptilian mammals from the Triassic of Virginia. *A*, *Dromatherium*, × 2; *B*, *Microconodon*, × 3. After H. F. Osborn.

From the evolutionary viewpoint, the most interesting Triassic remains are the lower jaws of diminutive reptilian mammals, found in Virginia and Europe (Fig. 359). Mammals are the most highly organized animals, but these, their earliest known representatives, were very small, and, like their reptilian forebears, low in mentality, giving little promise of being the future conquerors of the world.

CHAPTER XXXIV

LAND REPTILES AND TOOTHED BIRDS OF MEDIEVAL TIME

Dinosaurs

Bird-like tracks on the red sandstones of Upper Triassic age have long been known in the quarries of the Connecticut valley (see Fig. 358). Some of these tracks are but an inch long, and others about 2 feet. Many of them are so like those made by three-toed birds that the geologists of the first half of the past century regarded them as made by birds. Now, however, they are known to have been made by reptiles, and chiefly by dinosaurs, which ran on their hind legs as do the birds. The last of the dinosaurs died out with the Cretaceous.

The Mesozoic lands were so dominantly under the control of these "terrible reptiles" or dinosaurs, so named by Sir Richard Owen,

Fig. 360. — Restorations of the largest known carnivorous "king-tyrant" dinosaur, *Tyrannosaurus rex*, and of horned herbivorous dinosaurs (*Triceratops*), from the late Cretaceous of Wyoming. After H. F. Osborn and C. W. Gilmore.

that the era is usually referred to as the Age of Reptiles. The dinosaurs were the most extraordinary animals the world has ever seen, as diversified in form and size as are the living mammals. Probably all were egg-layers. Among them were huge beasts of prey with bird-like feet and eagle-like claws, running on their hind legs after the fashion of ostriches (Fig. 360); associated with these were other bipedal dinosaurs, but of sluggish habits and with duck-billed muzzles, feeding on the vegetation of the swamps and water places; hugest of all were the sauropods (see Fig. 361), vegetarians

walking on all fours, with more or less pillar-like legs, long snake-like necks, long tails, and a brain weighing less than a pound to govern a body with a weight of about 40 tons and a length of 60 to 80 feet.

Most curious of all, however, were the armored types, covered with plates and spines; these were also plant-feeders and quadrupedal in gait (Fig. 363). Finally, toward the close of the medieval era there appeared a very diversified horde of large rhino-like forms known as the ceratopsians (Fig. 360). It is these many kinds of strange medieval brutes that we are to study in this chapter.

The Carnivorous Theropoda. — The primitive light-bodied, long-necked, and long-tailed type of dinosaur, of carnivorous diet, occurs for the first time in the Upper Triassic sandstones of the Connecticut valley. This animal is known as *Anchisaurus* ("near-lizard"). Out of this type developed the later flesh-eating forms, all of which were also bipedal in locomotion, with their greatest variety in Jurassic time. Their fore limbs were often absurdly small in proportion to those behind and were used for catching, holding and tearing the prey. The hind limbs were long and powerful, the larger bones hollow as in other active beasts of prey, and the feet were bird-like. The claws were long, curved and sharp like those of eagles, hence the name Theropoda, which means *beast-footed.* The teeth were sharp, slightly curved and dagger-like, often with serrate cutting edges to add to their terribleness. No fiercer biting head was ever evolved than that of the king-tyrant saurian, *Tyrannosaurus rex* (Fig. 360), of the latest Cretaceous of Montana and Wyoming — in respect to speed, ferocity and bodily size, the most "destructive life engine ever evolved." In size the Theropoda ranged from several feet long, measured along the back, to 47 feet in *Tyrannosaurus*, with a height in the latter of 18 to 20 feet, and a weight exceeding that of the elephant. The skin in the Theropoda was probably naked, at least it was not defensively armored, though in some cases there may have been scales as in snakes.

The Giant Sauropoda. — The sauropods ("reptile-footed") were ponderous animals and heavy of foot. They attained a world-wide distribution, being best known in the late Jurassic of North America and East Africa, and in late Cretaceous beds in the United States and western Argentina. The greatest of these was *Gigantosaurus* of East Africa, the largest land animal known, with a length of some 80 feet, 36 feet of which was neck, and a live weight of something like 40 tons. In this form alone the fore limbs were longer than the rear ones. The American *Brontosaurus* ("thunder saurian," Fig. 361) was about 65 feet in length, but heavier in construction,

weighing some 37 tons. It also had a long tapering neck and tail. The brontosaurs are thought to have lived for the most part in swamps of river valleys (Rocky Mountains) and in fresh-water marshes along the sea-shore (Africa), detaching the swamp plants with the claws and swallowing them without mastication.

Diplodocus (so named from the vertebræ, which are double-beamed) was lighter in build though long and slender, with 10 of its 80 feet of length taken up by a whiplash-like tail of unknown use.

Fig. 361. — Restoration of the gigantic late Jurassic sauropod dinosaur, *Brontosaurus*, of Wyoming. Weight of animal, about 38 tons. After H. F. Osborn.

The ponderous size must have given it a certain immunity from attack, while its chosen haunts kept it out of competition with fiercer kin.

The Bipedal Herbivorous Ornithopoda (see Fig. 362). — The Ornithopoda ("bird-footed") had no front teeth, but the muzzles terminated in a horny sheath, making a beak as in ducks or turtles. These forms lived for the most part in water, where they cropped the plants with the sharp edges of their toothless beaks. In the back part of the jaws were wonderful magazines of teeth, long in sequence, and superimposed several deep, with which they ground the food plants before swallowing them. When these teeth were completely worn away through grinding at the top, new ones came up from beneath to take their places.

The hind legs of the bipedal herbivorous dinosaurs were large and powerful, and on land were the essential means of locomotion. Their

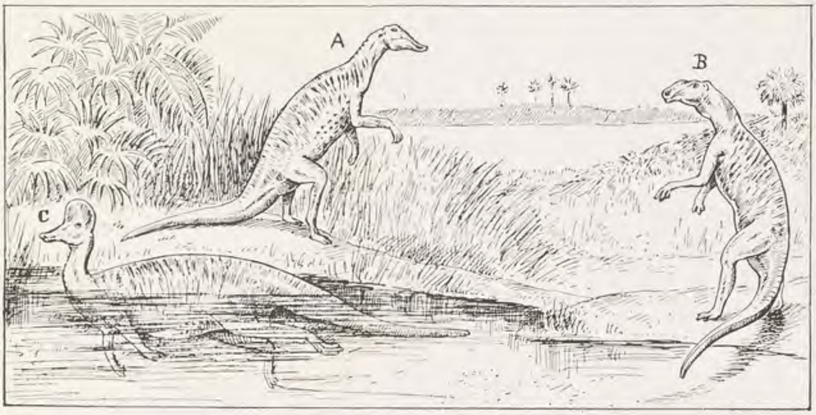

Fig. 362. — Restorations of "duck-bill" dinosaurs of the late Cretaceous of Alberta, Canada. *A*, typical "duck-bill," *Trachodon; B*, hooded "duck-bill," *Corythosaurus; C*, crested "duck-bill," *Kritosaurus*. After Brown and Deckert, from Osborn.

hands were webbed, and used for paddling, and the long tail was flattened and served to scull about in the water as do the alligators. The duck-bill mouth is further evidence that they dwelt much in water.

The Armored Stegosauria (see Fig. 363). — In Jurassic time there developed out of the duck-billed forms a most bizarre stock of heavy-limbed quadrupedal animals, browsing on leaves and twigs. These were the plated and armored types. Their habitat appears to have been completely away from the water on the dry land, where they were subject to the attacks of their carnivorous colleagues, hence the necessity of a protective armor. They returned to the ancestral locomotion on all fours, and specialized in the production of an elaborate series of bony outgrowths of the skin.

Fig. 363. — Restoration of an armored herbivorous dinosaur, *Stegosaurus*, from the late Jurassic of Wyoming. Weight of animal, about 10 tons. After C. W. Gilmore.

In *Stegosaurus* ("covered saurian," see Fig. 363) the almost impregnable armor consisted of a double row of variously large bony plates ranging down the back from the head to near the end of the lashing tail, there to be replaced by two or more pairs of long sharp spines, making the tail a "huge battle mace." All of these bony outgrowths were provided with horny sheaths. Over the hip area the plates were more than 2 feet high, 30 inches long, and 4 inches thick at the base. The tail spines attained to a length of about 2 feet. In the skin were other bony nodules. Doubtless when the stegosaurs were attacked, they drew their head and limbs under the body as do the armadillos and porcupines, and for protection against their enemies relied upon their dorsal armature, aided by rapid lateral motions of the great tail with its series of spines. They died out during the Cretaceous, and appear to have been restricted to North America.

In this form the small size of the brain in proportion to the body weight, which is characteristic of the dinosaurs in general, is especially noticeable, the brain weighing but $2\frac{1}{2}$ ounces as against fifty times that weight in the elephant of lesser bulk.

The Horned Ceratopsia. — Probably the most interesting of all dinosaurs are the horned types, "strictly American products," first discovered in Wyoming and Colorado. These horned forms are characterized by the hugeness of the heads, in contrast to the comparatively small ones in other dinosaurs. The first form discovered was called *Ceratops* ("horned face"), and this has given the name to the group. They looked somewhat like rhinoceroses. The body was usually very large, barrel-shaped, with four short but stout legs. The tail was massive, but relatively short. The heads were wide and long, being drawn out backward over the neck into a prominent protective frill, usually 4 to 6 feet long but reaching 8 feet in *Torosaurus*. In some there was a short and in others a long horn over the nose, and over the eyes there were other horns, which again may be long or short. In *Triceratops* (see Fig. 360), there were three prominent horns. Some of the horns had a length of 3 or even 4 feet, and all the cores of bone were sheathed in horn. In addition, there were still other smaller horns along the edge of the frill, or the latter was drawn out into long horns. The muzzles were also covered with horn as in turtles, and the jaws were replete with cutting teeth. The brain did not exceed 2 pounds in weight.

The ceratopsian stock originated in Asia, but all the horned forms appear ready-made in the Upper Cretaceous (Judith River) of the Great Plains of North America and were among the last of the dinosaurs to die out. Some of them were larger than elephants, weighing in the flesh up to 10 tons.

Pterodactyls

After the dinosaurs, the most extraordinary and characteristic animals of the lands during Mesozoic time were the dragons of the air, known as pterodactyls. These flying reptiles were more or less bird-like in appearance, and flew perhaps even better than the associated medieval birds. The largest ones had the extraordinary wing-spread of 25 feet. The skeleton, however, was of very light construction, and it is probable that even the largest forms did not exceed 30 pounds in live weight; their bodies were, in fact, but an appendage to a pair of wings.

The heads were usually much elongated, and the jaws generally provided with an abundance of slender, pointed and more or less

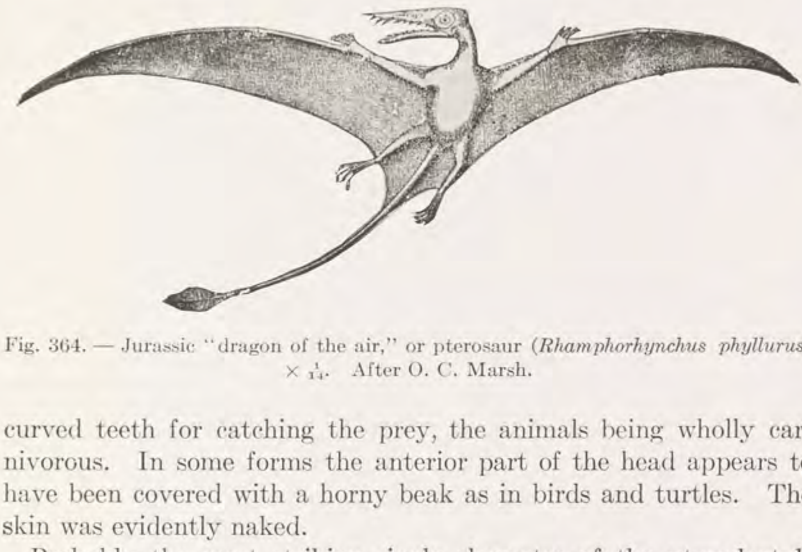

Fig. 364. — Jurassic "dragon of the air," or pterosaur (*Rhamphorhynchus phyllurus*) $\times \frac{1}{14}$. After O. C. Marsh.

curved teeth for catching the prey, the animals being wholly carnivorous. In some forms the anterior part of the head appears to have been covered with a horny beak as in birds and turtles. The skin was evidently naked.

Probably the most striking single character of the pterodactyls was the elongation and modification of the front limbs into flying organs. This was especially true of the fourth or wing finger, which in the genus *Pteranodon* reached a length of 5 feet. To this was attached the wing membrane, a very flexible leathery skin like that of bats.

Skeletons of pterodactyls occur in greatest variety in the Jurassic strata of western Europe. In America, single bones are known in late Jurassic deposits, but the group attained its maximum in the Cretaceous, when *Pteranodon* sailed far out over the chalk seas of Kansas.

Toothed Birds

Birds appear as fossils for the first time in the Upper Jurassic, and represent one of the most remarkable advances which the life of this period has to show. As yet, only a single kind of Jurassic bird has been found, and this is from the highest division, near Solenhofen, Germany. This bird, about the size of a large pigeon, is called *Archæopteryx*

Fig. 365. — Head of *Archæopteryx*, as restored by Heilmann.

Fig. 366. — Swimming reptilian bird (*Hesperornis regalis*) from the Upper Cretaceous of Kansas. Restoration by Gerhard Heilmann.

(Greek for *ancient wing*). It has many points of resemblance to the reptiles, and many characters which recur only in the embryos

of modern birds. The jaws were set with a row of small teeth (see Fig. 365).

The first American birds come from the early Upper Cretaceous strata of Kansas. These are large reptilian water birds of a species which has been called the " regal western bird " (*Hesperornis regalis*, Fig. 366). They are also distinguished at once from modern birds by the possession of teeth. *Hesperornis* stood about 4½ feet in height; its wings were vestigial and of no use in air or water, but the great feet were webbed. Associated with these are found very rarely other smaller toothed birds with powerful wings (*Ichthyornis*, Fig. 374), which looked much like modern gulls and terns. All of these birds were flesh-feeders.

CHAPTER XXXV

THE JURASSIC PERIOD AND THE MANY KINDS OF REPTILES

In Europe, over the Triassic lies the widely distributed and usually but little disturbed Jurassic. The high lands that were made during the close of the Paleozoic had now vanished, and extensive epeiric seas, with a life that was astonishingly rich and varied, gradually spread over the continent. Probably as many kinds of fossils are known from Jurassic rocks alone as from all the other Mesozoic strata combined, and because of this prevalence of organic remains, these formations have been the training ground for many European stratigraphers and paleontologists. In England, these deposits furnished fossils to William Smith, the Father of Stratigraphic Geology, who was the first to discern in them a value as aids in determining the age of the containing strata. In fact, it is from the Jurassic deposits of England, Germany and France that the principles upon which Stratigraphic Geology depends have been worked out.

From the studies of the abundant Jurassic marine faunas, and chiefly the ammonites, came also the first clear ideas of climatic zones in Geology and of paleogeographic maps.

North America, however, stands in strong contrast to the European Jurassic development, for the record is one of erosion and peneplanation over three-fourths of this continent. It was only in Mexico and in the western portion of the continent that the ocean invaded the land. Probably fewer than 600 kinds of Jurassic fossils have been described from North America, while Europe has made known nearly 15,000 forms.

Jurassic Seas. — In a previous chapter we saw that the Triassic period in eastern North America closed with the Palisade Disturbance, a movement that resulted in the making of block mountains, probably somewhat lower than the present Sierra Nevada. Accordingly, Jurassic time here opened with active erosion, and whatever continental deposits were formed at the time were swept into the Atlantic Ocean. This erosion cycle brought about the final transformation from the previous topographic expression of high Appalachian and lower Palisade mountains to a nearly base-leveled land, thus

preparing the way for the next overlap of the Atlantic Ocean, late in Cretaceous time.

On the Pacific border also the Triassic period closed with emergence, but early in the lower Jurassic, the Pacific Ocean again began to invade North America, sparingly in the Aleutian Peninsula, the Cook Inlet country of Alaska, and across Vancouver Island. These areas are of the *British Columbic geosyncline*, and in Alaska the invasion continued throughout Jurassic time, depositing here about 10,000 feet of coarse deposits, along with tuffs and andesitic lava flows. The widest extension in early Jurassic time, however, occurred in the Californic sea of Oregon, California and Nevada.

Toward the close of the Middle Jurassic, the northern Pacific, with a cool-water fauna, began to spread widely over Alaska, throughout the British Columbic geosyncline and into the Rocky Mountain geosyncline in the states of Montana, Idaho, Wyoming, Colorado and Utah (Pl. 21, Map 3). This flood has been given the name of *Logan sea* and the nature of its deposits changes from place to place. They consist of sandy clays, shaly marls, impure limestones and sandstones that are much cross-bedded; these, along with the universal presence of oysters, indicate that the sea was a shallow one.

Late in the Triassic the Gulf of Mexico spread northwestward into northern Mexico, and in the late Middle Jurassic the greater central part was flooded. We shall see further periodic floodings in the Mexican geosyncline throughout later Mesozoic time (see Pl. 23). Here the Jurassic sediments in the main are limestones and abound in ammonites.

Continental Deposits. — Overlying the marine Jurassic throughout the Great Plains country, from Montana south into New Mexico, occur variegated green and red marls and shales with irregularly distributed beds of sandstone. These are the Morrison continental deposits (Pl. 21, Map 4), so called because they were first studied at Morrison, near Denver, Colorado. They yield only fresh-water bivalves, snail shells and some reptiles, along with land plants, but the most striking fossils are the dinosaurs and some archaic mammals. These deposits are thought to have been laid down over a comparatively low and level plain which was occupied by lakes and swamps connected by an interlacing system of river channels, in which most of the dinosaurs lived. The topography and climatic conditions of that time are held to have been much like those of the lower reaches of the Amazon to-day.

Volcanic Activity. — The volcanic activity which marked the Pacific border of North America during Middle and early Upper

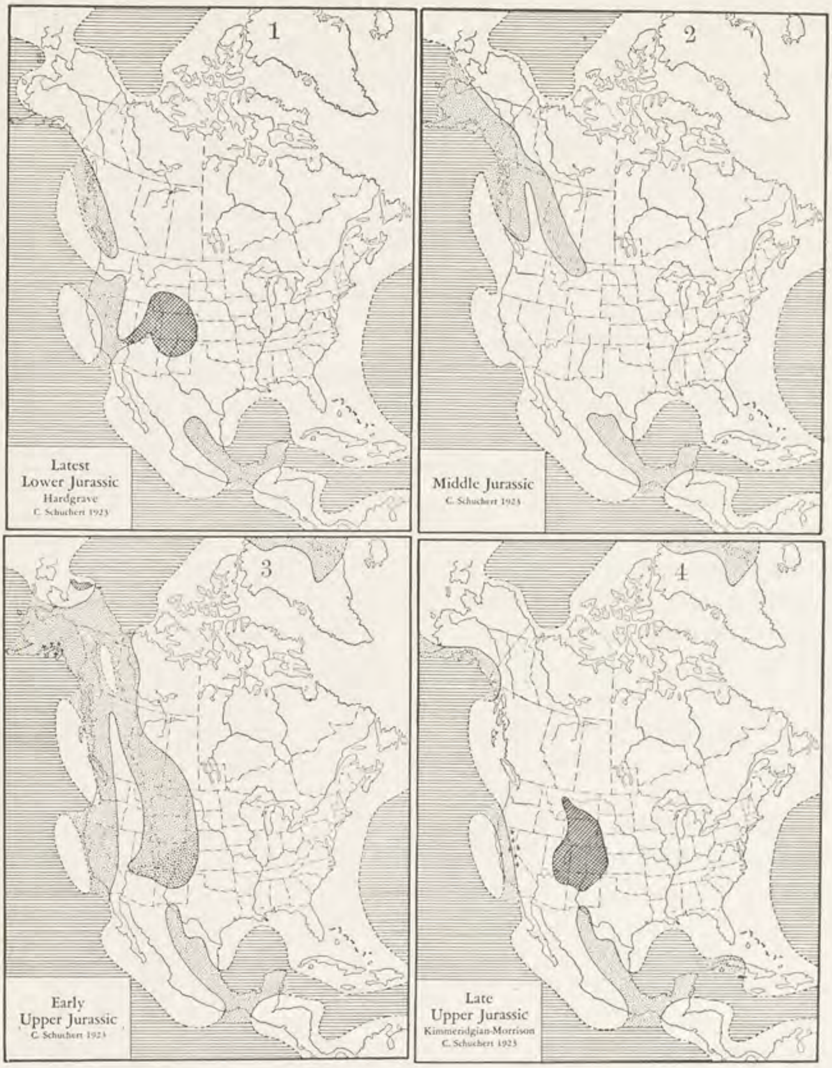

Plate 21. — Paleogeography of Jurassic time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled. Volcanic regions indicated by crosses. See Plate 22 for latest Jurassic physiography.

Note that the entire sedimentary record is in the western part of the continent, Central America, and Cuba. In Map 3 is shown the spread of Logan sea, with gypsum and red beds in darker shading. The highly interesting dinosaurs of the Morrison strata are found in the cross-ruled area of Map 4.

Triassic time began again locally early in the Jurassic and continued throughout the period, becoming even more wide-spread toward its close than at any previous time (see Pl. 21). The eruptions were in part submarine, and in the main followed the distribution of the Triassic volcanoes.

Nevadian Disturbance. — Toward the close of the Jurassic, the Pacific System of mountains (Sierra Nevada, Coast Ranges of California and British Columbia, Humboldt, Cascade and Klamath mountains) was elevated. This very decided movement is called the Nevadian Disturbance. With the rise of these mountains to the east and west, there came into existence between them the Great Valley of California, a narrow but long geosyncline that has persisted into the present. Although the mountains mentioned appear to have been the regions of most active deformation, it seems probable that movements more or less marked took place from Mexico into northwestern Alaska. (See Pl. 22.)

While the Pacific border of North America was being folded, the earth-shell was also invaded by deep-seated igneous rocks (granodiorite) on a very large scale. At the surface there were immense outpourings of lava, which are conspicuous in the present Sierra Nevada. Magmas in great volume were intruded, forming the great chain of bathyliths now exposed by erosion along the Pacific border from Lower California to the Alaskan Peninsula (see Pl. 23, Map 1). In comparison with this intrusion, all post-Proterozoic ones fade into insignificance. It is thought that although these intrusions may have started in Middle Jurassic time, the main injections took place at the close of the period, extending into Lower Cretaceous time, and that less significant upwellings went on even to the close of the Mesozoic era.

The gold-bearing veins of quartz in the rocks of the Sierra Nevada formed as a result of the igneous invasions. The opened spaces and fissures became filled with silica (quartz) deposited by the heated solutions coming from the bathyliths below, which also brought with them the ores now found in the veins. Their erosion has furnished the gold found in the sand of rivers flowing out of the mountains (see p. 431). The ores in the Coast Ranges of British Columbia likewise date from this time.

Eruptions of volcanic rocks on a tremendous scale also occurred during the Jurassic in South Africa and eastern South America, marking the first stage in the breaking down of the transverse continent Gondwana. The foundering of this old land was completed in Cretaceous time.

Plate 22. — Late Jurassic paleophysiography.

The probable geography of late Jurassic time, when the Sierra Nevada and other mountains of the Pacific System were rising (see p. 599). The Central Cordilleran ridge to the east of these mountains was rising, but is here drawn too high, while the Coloradic or Rocky Mountain geosyncline is shown as too deep. Note that the Appalachians are greatly reduced (compare with the map on p. 562), and that the Mississippi drainage may have begun this early.

Life of the Jurassic

In the Jurassic, about 1000 species of insects are known, as against fewer than 50 in the Triassic. True butterflies (Fig. 367) and flies were rare in the Lower Jurassic, but caddis-flies, scorpion-flies, dragon-flies and beetles were abundant. Other kinds of insects known from the Jurassic are the cicadas, grasshoppers, locusts, cockroaches and termites. The social ants were certainly present in the early Jurassic, arising out of primitive wasps of the kind that now live in deserts or hot sandy places.

Fig. 367. — An Upper Jurassic butterfly (*Limacodites mesozoicus*), as restored by A. Handlirsch. From *Geschichte der Entomologie*, 1922.

The Jurassic reptiles attained a more diversified development than those of the Triassic. True lizards appeared here, and the turtles were abundant and world-wide in distribution. One of the most remarkable groups of Jurassic carnivorous reptiles was that of the flying dragons, which are described in the previous chapter. The dinosaurs probably attained their zenith of differentiation in the late Jurassic and then continued in fullness of development into the Cretaceous. The most characteristic of all were the Sauropoda, and other striking large forms occurred among the carnivores and armored types, described in the preceding chapter. In this chapter we also saw that the first known birds come from Jurassic strata (*Archæopteryx*, Fig. 365).

Among the reptiles of the seas, the Ichthyosauria (fish-lizards) were a highly characteristic group, for though they appeared in the Triassic and continued into the Cretaceous, the Jurassic, and especially the Lower Jurassic, was the time of their principal expansion (Fig. 368).

Among the marine invertebrates, sponges were locally very common, and in places made thick reef limestones. Other reefs were made by modern corals (Hexacoralla, Fig. 369), which were of very wide distribution in the Middle and early Upper Jurassic. The crustaceans, usually rare as fossils, are represented by many kinds of lobsters and the first crabs in the Upper Jurassic about Solenhofen, Germany, due to unusually favorable conditions of preservation. The most characteristic shell-fish of the Jurassic, however, were the ammonites.

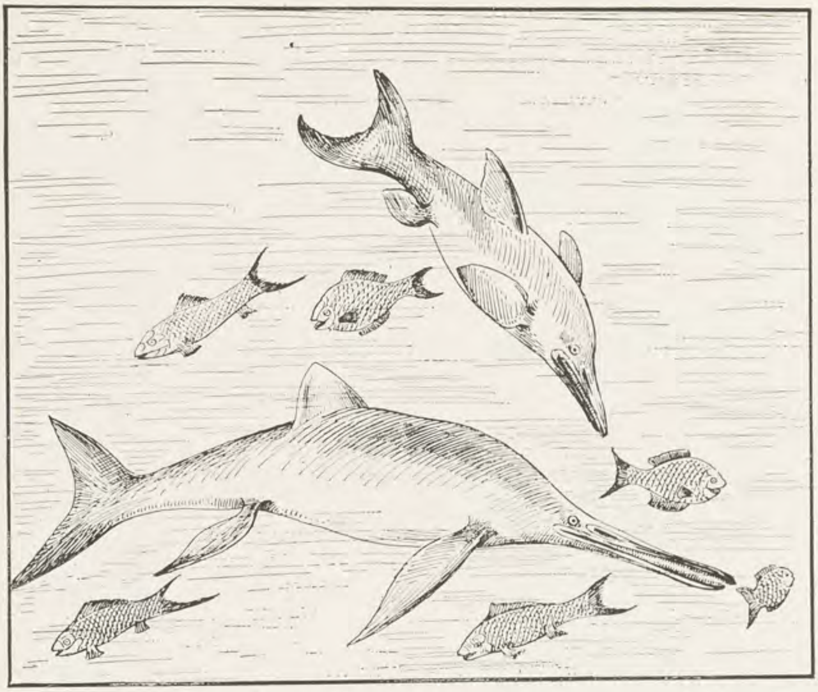

Fig. 368. — Restorations of early Jurassic fish-lizards feeding on ganoid fishes. The long-snouted type (*Ichthyosaurus longirostris*) and the short-headed one (*I. quadriscissus*) are both found in Germany. From E. Hennig's Guide to the University of Tübingen Museum.

Fig. 369. — Two kinds of Jurassic reef-making Hexacoralla. On right, *Latomæandra seriata;* on left, *Thecosmilia trichotoma.*

Ammonites belong to the class Cephalopoda, and hence are related to the Paleozoic nautilids (described on page 523), to the belemnites, and to their descendants, the modern cuttle-fishes and squids. They arose out of the goniatites (Pl. 12, Figs. 18–20), occurred in the Mesozoic seas in great abundance, and were exceedingly varied in size, shape and ornamentation. Probably the average size was between 3 and 4 inches, although one form in the Upper Cretaceous of Germany (*Pachydiscus seppenradensis*) attained a diameter of 8 feet. They appear to have been better swimmers than the nautilids, and therefore crawled less over the sea bottom. The name comes from a fancied resemblance of the shells to the horns of rams, pictured as one of the attributes of the Egyptian deity Ammon.

Fig. 370. — Jurassic ammonite with the animal restored. Rostrum shown in right-hand figure. From Fraas's Guide to the Stuttgart Museum.

In many ways the chambered shells of the ammonites resemble those of the pearly nautilus, but there are a number of marked differences. The former are nearly always more ornate, narrower or less deep, often distinctly keeled, and usually this keel is drawn out into a sharp point, the rostrum (see Fig. 370). The chief difference, however, is in the nature of the partitions (septa) between the chambers of the shell, which attain a much greater degree of complication in the ammonites than in the earlier nautilids. The edge of these septa, as it appears in the fossils, in which the outer shell is often absent, has so distinct and complicated a pattern in the various forms that it makes the ammonites especially valuable in deciphering the chronology of the Mesozoic, since this complication is progressive with time.

Belemnites were also characteristic of the Mesozoic, and were the ancestors of the modern squids. They were likewise very active, carnivorous cephalopods which fed on fish, crabs and molluscs, but unlike the ammonites, they had no external shells. They had ten arms, possibly eight short and two long protrusible ones, as in the living squids. Among fossils, the part of the internal skeleton usually preserved is the *guard*, a more or less cigar-shaped, solid, calcareous body, sometimes 2 feet long and 4 inches thick (Pl. 20, Fig. 3).

CHAPTER XXXVI

CRETACEOUS TIME AND THE APPEARANCE OF FLOWERING PLANTS

In the early part of the past century the European geologists were struck by the wide distribution of chalk deposits overlying the Jurassic and beneath the Cenozoic, and therefore characterized them as the Cretaceous system, from the Latin *creta,* chalk. In the course of their work in England and France, they added formations of other materials, because the fossils clearly linked them together. In this way the Cretaceous system came to embrace so great a mass of heterogeneous strata that with the continued increase of knowledge it became necessary to separate the formations into Lower and Upper Cretaceous divisions. This usage is now widely accepted.

Chalk was long believed to be an abyssal oceanic deposit like the present Globigerina ooze found over great areas of the ocean bottoms, but the larger fossils in the chalks are indicative of shallow seas, and the formations are often accompanied by sands, while in closely adjacent areas the equivalent strata contain no chalk. Accordingly, it is now held that chalks are accumulations of organic materials made in the main by the calcareous skeletons of minute plants (algæ) and animals (Foraminifera, see p. 559), in clear-water seas adjacent to low lands with mild or desert climates.

Lower Cretaceous Time

In North America, the Lower Cretaceous has two independent marine developments: (1) in the Mexican geosyncline, extending widely over Mexico and northward across Texas into Colorado and Kansas. This is the *Comanchian sea.* (2) A Pacific development known as the *Shastan sea,* of the Californic and British Columbic geosynclines. In addition, there are two widely separated areas of fresh-water deposition: (3) the Kootenai strata in the Canadian Rockies and rich in coal deposits, and (4) the Potomac strata, rich in pottery clays, along the border of the Atlantic in the United States (see Pl. 23).

Comanchian Sea. — From southern Arkansas across Texas, and thence across almost all of eastern Mexico to the Isthmus of Tehuan-

tepec, are found limestones and marls that are of Comanchian age. These are the deposits of the most extensive inundation by the oceans which befell Mexico and which was greatest here in middle Lower Cretaceous time. Central Texas is the typical area for these strata, and in the southern part of that state and in Mexico the Comanchian seas are thought to go unbroken into those of the Upper Cretaceous. Late in Comanchian time the sea of the Texan area began spreading northward across New Mexico and Oklahoma into Kansas and Colorado (see Pl. 23, Map 2). The thicknesses of deposits here are usually less than a few hundred feet, which toward the north and east thin down to the vanishing point.

Shastan Sea. — The Shastan development is wholly distinct, faunally and lithologically, from the Comanchian one, from which it is separated geographically by the Central Cordilleran geanticline (see Pl. 23, Map 2). The faunas are of the Indo-Pacific realm. The Nevadian Disturbance at the close of the Jurassic had greatly reduced the width of the Californic geosyncline, making of it a narrow but deepened trough throughout western California, but extending widely into Oregon. To the west of the trough lay a borderland of which the present Coast Ranges are the remainder. Into this narrow trough the Shastan sea spread, depositing essentially sandy shales, the thickness of which attains to about 10,000 feet in northern California.

Shastan deposits are also known in northern Washington and along the Canadian and Alaskan coasts. These include considerable thicknesses of volcanic material (lavas, tuffs and ash beds), and in the Queen Charlotte Islands there is coal present.

Kootenai Continental Deposits. — Turning now to the areas of fresh-water deposition, we find in southern Alberta (Crowsnest Pass) and southeastern British Columbia, east of the axis of the Rocky Mountains, Lower Cretaceous formations of great thickness. These, the Kootenai swamp deposits, are chiefly sandstones and sandy shales. They contain many beds of good coal, estimated to total nearly 8,000,000,000 tons, of which about 400,000,000 tons is anthracite. The coal-bearing Kootenai is likewise present about Great Falls, Montana, and south into central Wyoming (see Pl. 23, Map 2).

Potomac Continental Deposits. — The second fresh-water area of deposition is best developed in Maryland. The rocks are exposed to the east of the Triassic outcrops and still further eastward they gradually pass beneath the later Cretaceous and Cenozoic strata. This formation is notable for its introduction of the flowering plants, which were to come in strongly in the Upper Cretaceous.

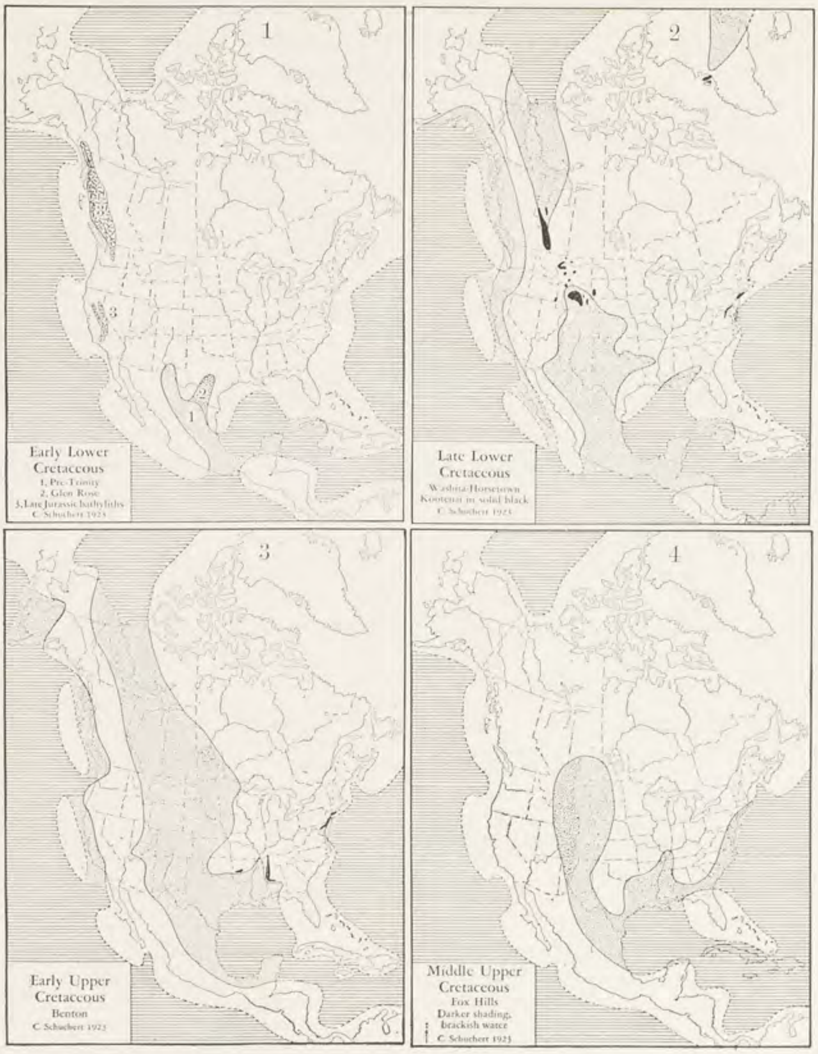

Plate 23. — Paleogeography of Cretaceous time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits in solid black.

In Map 1 are shown the more important areas of late Jurassic igneous intrusions. In Map 2, note the presence of the Cordilleran Intermontane geanticline, the small areas of fresh-water Potomac deposits along the Atlantic piedmont, and the far greater areas of river deposits in the Rocky Mountains. The greatest Cretaceous flooding is shown in Map 3, and the complete retreat of the seas follows, Map 4 and Pl. 24. Note the land bridge to South America in Maps 3 and 4.

Central Cordilleran Disturbance. — We have seen in previous chapters that the waters of the Pacific transgressed widely throughout the two western geosynclines of the North American continent during the Triassic and again in the Jurassic. In the Rocky Mountain area of the United States, however, uplift began as early as Middle Triassic time, apparently bowing up a low arch in western Utah, eastern Nevada and throughout Idaho (black area of Fig. 371), and this arch persisted into late Jurassic time. At the close of

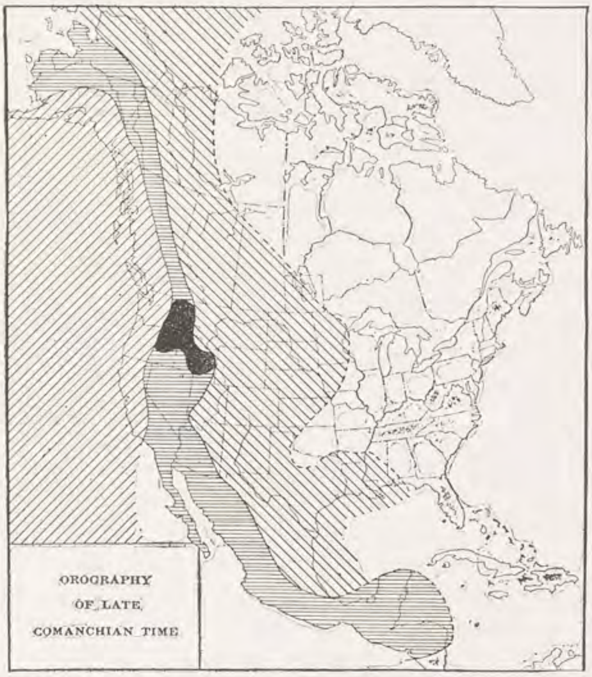

Fig. 371. — Outline map to show regions of elevation (horizontal shading and solid black), the formation of the Coloradic geosyncline (right-hand diagonal lines), and the Pacific deposits. Generalized from Ransome, *Problems of American Geology*. The black area is that of the present Columbia River Lava Plateau, the region of elevation to the north is known as the Northern Interior Plateaus, while that to the south is the Nevadan-Sonoran Region.

the Jurassic the Sierra Nevada was thrown up to the southwest of this uplift, narrowing the former wide extension of the Californic and British Columbic geosynclines. These conditions were further altered toward the close of the Lower Cretaceous by the additional rising of land to the west of the present main Rocky Mountain ridges, all these uplifts together making the Central Cordilleran Belt of elevated plateaus that extend from Arctic Alaska all the way

into Central America. This movement is the Central Cordilleran Disturbance near the close of the Lower Cretaceous. It was manifested also in Mexico, for in late Lower Cretaceous time western Mexico and Central America into Nicaragua were elevated. (See Fig. 371.)

Crustal unrest of this time is also apparent in other parts of the world, for toward the close of the Lower Cretaceous the Atlantic began to encroach upon Brazil and equatorial West Africa, showing that much of the continent of greater Gondwana had gone into the depths of the Atlantic. The present configuration of the Atlantic Ocean, may, therefore, be said to have had its origin in the early part of the Cretaceous period.

Upper Cretaceous Time

With the Upper Cretaceous, we come to a time of wide-spread flooding of the continent by a great epeiric sea, together with overlaps along the Atlantic, Gulf of Mexico and Pacific borders. The Upper Cretaceous transgression, the world over, was probably the greatest of all geologic time.

In North America, this vast epeiric or inland sea at first extended from the Arctic Ocean into southern Mexico, and from the Cordilleran highlands east almost to the Mississippi River (see Pl. 23, Map 3). To the west lay the Central Cordilleran highlands, which furnished nearly all the sediments for the sea to the east. All of that portion of the sea to the north of Texas is known as the Coloradic sea; south of New Mexico this continued widely into the Mexican waters which covered the eastern half of Mexico all the way to Tehuantepec.

Coloradic Sea. — The deposits of the Coloradic sea are very variable from place to place, and are notable especially for the amount of coal which they contain. In general, they are thickest in the west, where the materials came from the periodically rising Central Cordilleran highlands, so that brackish and even fresh-water deposits are more frequent here than in the eastern part of the sea, and here is the greatest amount of coal (humic and lignite). Throughout the Rocky Mountains there are more than 100,000 square miles of coal-bearing lands.

During the Upper Cretaceous, the Coloradic sea began to vanish from the Arctic southward, and nearly all of the western part of the seaways south of 55° N. Lat. changed from marine to fresh-water conditions. Within the United States, however, the seas of Upper

Cretaceous time continued until near the close of this epoch, and even then the sea reappeared for a short time, depositing the Cannonball formation. These oscillations and the general vanishing of the marine waters are prophetic of the coming Laramide Revolution.

Mexican Sea. — The Mexican sea was an extension from the Gulf of Mexico, and in its spreading we see clearly for the first time the appearance of the Gulf, but as a greater body of water than it is now. On the border line of Mexico (Eagle Pass), Upper Cretaceous time is fully represented, and its strata are also well developed throughout northeastern Mexico and as far south as San Luis Potosi. South of this region the formations gradually vanish, and none are known in southern Mexico and the greater part of Central America.

Atlantic Border. — In addition to this great flooding of the interior portion of the continent, the Cretaceous waters also overlapped upon its borders as shelf seas, laying down the first known shelf deposits in North America. Upper Cretaceous formations are known all along the Atlantic border, either beneath or inland of the Cenozoic marine strata, from Massachusetts to South Carolina (see Pl. 23, Map 4). They all dip seaward, though their original position is now warped, due to elevation in the west. The area yielding most information is in New Jersey and Maryland, where the strata consist in the lower half of gravels, sand and clays with lignite, while the upper portion is made up of clays and sands becoming more and more glauconitic and finally going over mainly into greensands. Glauconite is made in clear-water seas, and these sands are characteristic of the Atlantic overlap and at times are found in considerable quantities in the eastern Gulf border.

Gulf Border. — The seas coming in over the eastern Gulf border across Texas and Louisiana laid down Upper Cretaceous formations in the Mississippi trough from southern Illinois across Tennessee and Mississippi into southern Alabama and Georgia. Nearly everywhere they overlap Paleozoic strata and in Georgia they rest on the ancient crystallines (Pl. 23, Maps 3, 4). The deposits begin as a rule with sandstones that pass into clays and marls and locally into thick impure chalks.

Pacific Border. — On the Pacific border the Lower Cretaceous (Shastan) strata are overlain by the Upper Cretaceous (Chico) sandstones and shales, with local conglomerates and coal beds. These occur in the British Columbic geosyncline all the way from the lower Yukon, the Alaskan Peninsula, and the Queen Charlotte Islands (11,000 feet) to Vancouver Island; and in the Californic geosyncline from middle and southern Oregon as far south as 31° 30′

Plate 24. — Latest Cretaceous paleophysiography.

Oceans ruled; lands in wavy lines.

Note that the continent is completely emergent, and that in the west it is newly risen into the Rocky, Cordilleran, and Pacific mountains (p. 612), while in the east the Appalachian area is again domed. Antillis and Central America also are mountainous.

The black spot is the area of latest Cretaceous fresh-water deposits. The drainage of the Mississippi system is well established.

(see Pl. 23, Map 3). In California there were two periods of volcanic activity, and in the Queen Charlotte Islands one of long endurance.

Laramide Revolution. — The close of the Cretaceous, and hence of the Mesozoic era, was marked by an extraordinary amount of mountain making in many parts of the world (see Fig. 372). In our

Fig. 372. — Stereographic map of the western hemisphere, after Penfield, showing the Laramide, Antillian, and Andean regions of folded mountains of Cretaceous origin. The Appalachian area was reëlevated but not folded.

own continent we have seen that the Central Cordilleran highlands had been rising intermittently since the Middle Triassic. This continued during the Upper Cretaceous and at times the geanticline was studded with active volcanoes that extruded much lava. These eruptions continued with unabated vigor to the end of Cretaceous time, and even into the early Eocene, and the volcanoes extended from Mexico City and Arizona north into Canada.

These volcanic eruptions were but symptoms of crustal movements, for mountain making of a folding nature, and thrusting toward the east on a vast scale (see p. 367), were going on during late Cretaceous time, resulting in the rising of the Rocky Mountains. The most intense folding, the actual Laramide Revolution, which closed the period and the era, transformed the geosyncline to the east of the Central Cordilleran highlands into the very long Rocky Mountains proper and the Colorado Ranges.

.The western part of South America was also involved in this mountain-making movement. During the Paleozoic and Mesozoic there existed here a geosyncline, containing the Andeic inland sea, to the west of which stood a wide and repeatedly rising highland furnishing rock materials. To the east of the sea lay a very extensive lowland, the Amazonian Shield, which in its history repeats the plains topography of the Canadian Shield. In the middle of Upper Cretaceous time, the Andeic geosyncline began to fold and rise into a mountain tract, the longest in the world. Beginning east of Trinidad off Venezuela, these mountains, the mighty Andes, extend southwestward into Colombia and thence southward to beyond Cape Horn, a distance of nearly 5000 miles.

During the Cretaceous, and more especially in the Upper Cretaceous, came the downbreaking of the lands bordering the Indian Ocean, and the development here of the present geography. The first clear evidences of this foundering of the lands bordering the Indian Ocean are seen in the volcanic eruptions of Arabia in early Upper Cretaceous time, and later in the period the belching forth of lavas became more general in India. These are the most colossal eruptions known to geologists, covering at least 200,000 square miles of India, as well as vast areas now buried in the depths of the Arabian Sea.

Climate of Cretaceous Time

The marine faunas of the Lower Cretaceous were not of warm waters in the far north, for no coral reefs are known there, but their distribution was then in higher latitudes than it is now. In general we may say that after early Upper Cretaceous time, when the marine floods were greatest, the climate the world over was considerably milder than it is at present, and that it was warm temperate in character.

Late in the Cretaceous, fig and breadfruit trees and palms were living in the Great Plains, indicating a climate as mild as that of to-day along the Gulf of Mexico. The climate in the Rocky Moun-

tains at the end of the period was again cooler, with distinct though probably not severe winters, more like those in the present Dismal Swamp of Virginia and North Carolina.

Life of the Cretaceous

The most striking aspect of the land life of the Cretaceous was the full development of the modern floras, along with the culmination of the dinosaurs, pterosaurs, toothed birds and archaic mammals. The floras held the prophecy of modernity, while the animals retained the culminating evolution of medieval life.

The floras of the Lower Cretaceous are everywhere divisible into an early and late phase of development. The older ones are those of the Jurassic retained into Cretaceous time, and consist of ferns, rushes, cycads and conifers. The rushes, however, had now dwindled into their present meagre representation, and the older Mesozoic ferns were giving way to modern ones. Finally, in late Lower Cretaceous time the cycads also began to wane, and their places were taken by the modern flowering plants or angiosperms. Before the close of the Lower Cretaceous, this early hardwood forest had spread to Alaska, Greenland and Portugal, where elms, oaks, maples and magnolias occurred; and later, in the earliest Upper Cretaceous, it spread over the entire world. *Its advent was as important in the plant world as was that of man among the animals.* Fruits, grasses and cereals were now at hand and these are of prime value to many animals, and especially to humanity. It seems more than a coincidence that angiosperms should have arisen and become world-wide in dispersal before the widest deployment and most significant evolution of the mammals took place, and we may well believe that human civilization could not have evolved but for the presence of this group of plants.

The invertebrate life of the sea was not very different from that of the Jurassic, and only a few of the more marked changes need be noted. The sea-urchins were very varied and prolific in the warmer seas, and the heart-urchins attained their climax of evolution in the Upper Cretaceous. Among the bivalves, true oysters and many oyster-like forms (see Fig. 373) were very abundant, while all of the molluscs were taking on the expression of modernity, through the elimination of the old stocks. This is best seen among the ammonites, which were still plentiful in the Lower Cretaceous, but showed a great loss of vitality, in that few new stocks arose. By Upper Cretaceous time, racial old age was upon them, and they were

Plate 25. — Upper Cretaceous brachiopods (1, 2) and molluscs (3–16, 3–6 bivalves, 3, 4 oysters, 7–12 gastropods, 13–16 cephalopods or ammonids).

Fig. 1, *Terebratula harlani;* 2, *Terebratella plicata;* 3, *Ostrea larva;* 4, *O. lugubris;* 5, *Exogyra costata;* 6, *Inoceramus vanuxemi;* 7, *Turritella whitei;* 8, *Admetopsis subfusiformis;* 9, *Cancellaria malachitensis;* 10, *Cryptorhytis utahensis;* 11, *Pyropsis bairdi;* 12, *Aporrhais prolabiata;* 13, *Scaphites nodosus;* 14, *Baculites compressus;* 15, fragment of an adult of same species, to show suture line; 16, *Heteroceras stevensoni.* After Stanton, Whitfield, and Scott.

making their last stand, the bottom-living forms being the last to vanish.

The seas of Cretaceous time, as well as the lands, continued to be dominated by reptiles. In the latter part of the period, the ichthyosaurs were vanishing, but the plesiosaurs attained their culmination, for a form has been found in Kansas which had a length of 40 to 50 feet (*Elasmosaurus*, Fig. 374). Most interesting of the newly appearing marine animals were the scaled reptiles known as mosasaurs, which lived only during the Upper Cretaceous. These gigantic carnivorous lizards, ranging in length up to 35 feet, and with limbs modified into swimming paddles, swarmed in the shallow seas along the Atlantic and Gulf borders, and especially in the seas of Kansas (see Fig. 375).

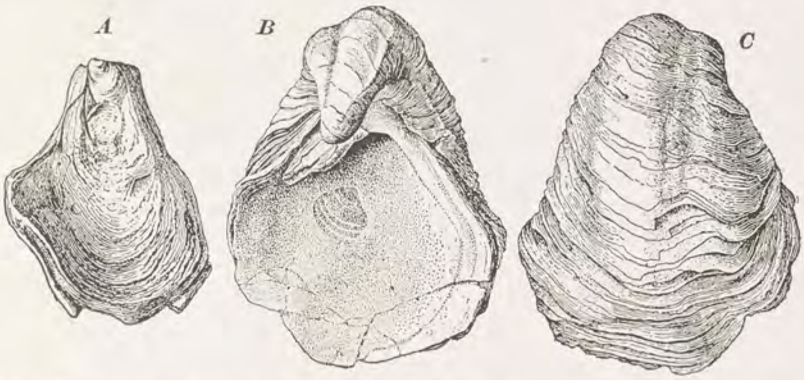

Fig. 373. — Oyster-like shells characteristic of the Comanchian (*Gryphæa mucronata*). After Hill and Vaughan, U. S. Geol. Surv. *A*, upper or free valve. *B*, and *C*, lower or attached valves from the inside and outside.

Almost nothing is known of the dinosaurs in the Lower Cretaceous other than fragmentary skeletons in the Potomac formation, though they are often present in equivalent formations in Europe. During Upper Cretaceous times, however, these reptiles were very varied and the individuals large in size. The most characteristic were the horned Ceratopsia. The duck-billed forms were large and represented by distinctively American kinds, both in the Rocky Mountains and in New Jersey. Large sauropods were rare. Upon these various kinds preyed the carnivorous types, among which was the king-tyrant saurian (*Tyrannosaurus rex*), the most fearful of all flesh-feeding animals (see Fig. 360). Not one of these monsters continued into Cenozoic time.

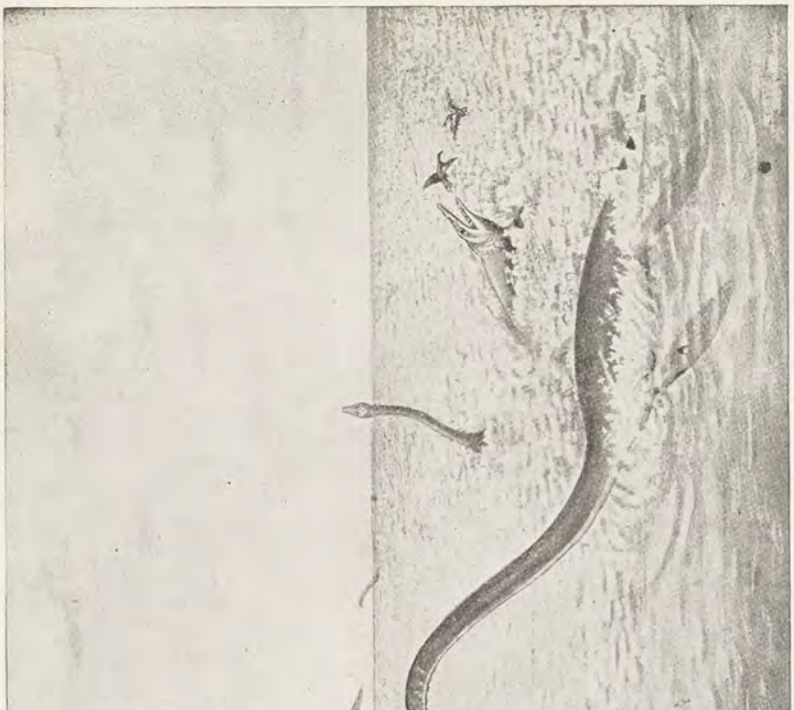

Fig. 374. — Restorations of vertebrates of the Chalk seas of Kansas. The long-necked reptile attacking the wingless reptilian bird (*Hesperornis*) is a plesiosaur (*Elasmosaurus*); the flying reptiles on the left are dragons or pterosaurs (*Pteranodon*); on the right is a fish-lizard (*Ichthyosaurus*), attacking winged reptilian birds (*Ichthyornis*). After Williston. From University of Chicago Press.

Birds are represented in the Cretaceous by the toothed forms described in an earlier chapter, and the flying reptiles, or pterodactyls, reached their culmination here in *Pteranodon*. Neither stock passed over into the Cenozoic.

Many jaws of diverse kinds of mammals have been found in late Cretaceous deposits of Wyoming and Montana, but they did not as yet play an important rôle among the land animals of their time; nearly all were small and of archaic character. Toward the very close of the Mesozoic, immediately after the dinosaurs had vanished, they began to attain larger size and tended to become the dominant animals of the lands. The most remarkable of these were five genera of primates, the stock from which man was ultimately to rise.

Fig. 375. — A scaled Upper Cretaceous mosasaur (*Clidastes*). From Kansas. Restoration by Williston, from University of Chicago Press.

The Cretaceous was a time of death to many characteristic Mesozoic stocks. Entire races of specialized forms disappeared, just as did other stocks under similar environmental circumstances (critical periods) at the close of the Paleozoic. In the later Cretaceous it was the ammonites, belemnites, marine saurians, dinosaurs, flying dragons and toothed birds that vanished, and there was marked reduction among the reef corals and ganoid fishes. In short, the reptilian dominance on land and sea was destroyed, and their going gave the medieval birds and mammals their chance to adapt themselves to the angiosperm floras and thus to rise into the rulers of the future Cenozoic world.

1. Flowering plant
2. Sorting of [illegible] forms [illegible] to latitude zones — adaptation to [illegible], climate + [illegible] topography
3. [illegible]
forms — birds also
4. Mammals — first [illegible] —

CHAPTER XXXVII

THE DAWN OF THE RECENT IN CENOZOIC TIME

Long ago a famous geologist said that the picture which Geology holds up to our view of North America during the greater part of Cenozoic time is in most respects more attractive and interesting than could be drawn from its present appearance. Then a warm and genial climate prevailed from the Gulf to the Arctic Ocean, and most of the continent exhibited an undulating surface of rounded hills and broad valleys covered with forests, inhabited by birds and animals far more varied than any of the present day, or wide expanses of rich savannah over which roamed countless herds of mammals, many of gigantic size, of which our present meagre fauna retains but few representatives.

During the rise of the science of Geology, the youngest era in the history of the earth was named Tertiary, it being thought that all older time was comprised in but two other eras. Later came into use the term Quaternary, which included the youngest geologic formations of more or less unconsolidated materials scattered over the surface of the earth. Since, however, Quaternary is not representative of an era of geologic time, and since we now recognize more than three eras, we had best abandon both Tertiary and Quaternary, and use only one term, Cenozoic (from Greek words meaning recent life). Recent time will then start when the Pleistocene continental glaciers began their final melting off northern Europe and North America, seemingly something like 20,000 years ago.

The separation of the Cenozoic into various subdivisions resulted from the study of the rich marine formations of the Paris basin, with their interbedded continental deposits. It became apparent as early as 1818 that the youngest strata had the greatest number of still living species, while the forms found in the oldest rocks had the least faunal resemblance to those of the present, and in the Cretaceous there were no species of the present living world. Hence the Cenozoic must be regarded as the era in which our present animal life dawned, and on the basis of the progressive change or evolution in its marine shells, it can be divided as follows: Eocene (dawn of the Recent), Oligocene (little of the recent), Miocene (less recent), Pliocene (more recent) and Pleistocene (most recent).

Seas

The seas of Cenozoic time in North America, excepting in California, were typically marginal overlaps of the oceans, and therefore of the nature of shelf seas. There were almost no inland or epeiric seas, in contrast to their dominancy during the Paleozoic and Mesozoic. The marine overlaps oscillated back and forth repeatedly and variably in the different areas of invasion, but at no time was more than 6 per cent (Middle Eocene) of the present area of North America under water, while the average for the Cenozoic was about 3 per cent or even less (see Pl. 26).

Atlantic Border. — On the Atlantic border, wherever the contact between the Cretaceous and the Eocene has been seen from New Jersey to central Mexico, the Eocene sea advanced across a land surface which had reached an old or nearly base-leveled stage of erosion, as is shown by the almost horizontal contacts. Not a single species of the Mesozoic is known to pass this break into the Eocene, indicating that the lost interval here is a long one.

The Cenozoic deposits of the Atlantic Coastal Plain north of North Carolina (Cape Hatteras) are not at all as well developed as those in the states bordering the Gulf of Mexico, and no Eocene strata are known north of New Jersey. A limited Lower Eocene development of marine greensands and marls not over 225 feet thick occurs in Maryland, Delaware and Virginia. Upon these follow, after a long interval of land conditions, the Chesapeake cold-water Miocene sands, clays, marls and diatomaceous earth, with a thickness ranging up to 475 feet (see Pl. 26, Map 3). Marine Pliocene strata are of very limited and occasional development.

From Cape Hatteras southward and westward, the marine Cenozoic is well represented, with the longest sequence of the older strata in Alabama and Mississippi and of the younger ones in Florida. In the north, toward the old shore, it is a variable series of sands, greensands (glauconite) and marls, with more or less of lignite beds, while in Florida occurs an unequaled development of Oligocene and Miocene limestones and marls, with but little sand.

Mississippi Valley. — In the embayment of the Mississippi valley extending to southern Illinois occur Eocene fresh- and brackish-water sands and clays, with beds of lignite (see Pl. 26, Map 1), the plant accumulations of former swamps. These are the sediments of the ancient delta of the Mississippi River when the shores of the Gulf of Mexico were near Cairo, Illinois. Later, in early Oligocene time, the sea had withdrawn to middle Alabama (see Pl. 26, Map 2).

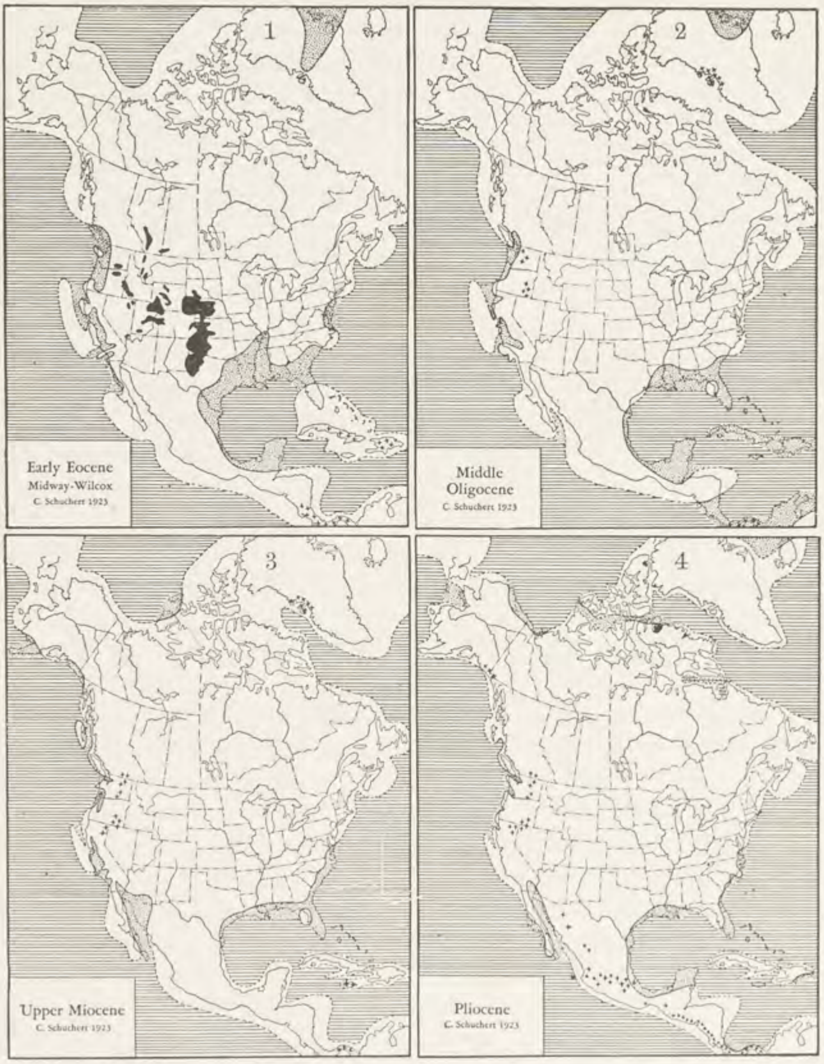

Plate 26. — Paleogeography of Cenozoic time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits with land life in solid black; these areas, however, have the combined Cenozoic formations. Volcanic regions indicated by crosses.

Note that all geosynclines have vanished excepting remnants of the Pacific one; also that North and South America are separated by the Panama portal, at the time of the greatest submergence of Antillis (Map 2).

Westward from the Mississippi River on the western Gulf Coastal Plain, the Eocene is well developed into Texas and northern Mexico, with marine, brackish-water and swamp deposits of sands, clays, greensands and lignite beds. Since Oligocene time the great stream of fresh water from the Mississippi River has not only had its influence on the sedimentation of this area, but has also prevented the intermigration of the shallow-water life to the east and west of the river.

The Oligocene formations are well developed in Louisiana, where they are essentially fresh-water sands and green clays. In Texas, marine Oligocene is well known in the oil wells, and in Mexico it occurs as narrow overlaps. West of the Mississippi, Miocene strata are known in deep wells, and at Galveston, Texas, they are 2300 feet beneath the surface, showing the extent to which the eastern margin has sunk beneath the sea since late Miocene time. Of Pliocene strata there is but a small development. (See Pl. 26, Map 4.)

Central America. — There are no marine deposits of the early Eocene known in Central America, and hence we may assume that at that time and during the late Cretaceous North America and South America were united by a land bridge wider than the present one. This connection permitted the land life of the two continents to intermigrate. During later Eocene time, however, and more especially throughout the Oligocene, the Caribbean Sea spread widely across southern Central America and some of the Atlantic Eocene molluscs migrated to California and South America. During the earlier Miocene the two continents still remained separated, and they were not reunited until late Miocene time. (See Pl. 26.)

Pacific Border. — On the Pacific side of the continent, most of our knowledge of marine Cenozoic invasions is restricted to the states of California, Oregon and Washington, and northward into the Vancouver area of Canada. There appears to be no sedimentary record along the shores of British Columbia and Alaska until late in Miocene times, and even this marine overlap was of small extent. (See Pl. 26, Map 3.)

In most places the Cenozoic rests unconformably upon the Mesozoic or older rocks, though at times the contact is a disconformable one. In California, there is a long Miocene record in very thick deposits, made up largely of ash and the siliceous tests of microscopic plants, the beautiful diatoms. About 25,000 feet of strata were accumulated here during the Cenozoic, but if we take the maximum thicknesses for all the formations the total rises to about 45,000 feet. In the main the deposits are coarse detritals, as sands,

muds and much volcanic ash with local lava flows. The seas were shallow and in places became filled with sediment and then passed into marshes, making coal beds, as was especially the case in the estuary of the Puget Sound region, where 125 coal beds occur.

It is not yet clear to what extent during the Cenozoic Alaska was united with Siberia, though it seems that the ocean did not invade the Bering Strait region until late in the Miocene. Since the Pliocene the bridge has been crossed by the sea at different times.

Continental Deposits of the Rocky Mountains

Fresh-water and wind deposits of Cenozoic time cover great areas in the United States, chiefly in the foothills and the plains country east of the Rocky Mountains (see Pl. 26, Map 1). It should be clearly understood, however, that the deposits consist of a large number of separated formations, laid down by many large and small rivers over their flood plains, now here and now there throughout the Cenozoic. As a rule, the strata remain horizontal and are somewhat consolidated into sandstones, sandy shales and local conglomerates. Volcanic ash in thick beds or reworked by water and wind occurs in most of the formations and constitutes a considerable amount of the Cenozoic rocks of the plains country. Nearly everywhere the strata are exposed to view in more or less locally dissected places where the rain, streams and wind of the present semiarid climate have worn them into those picturesque areas known as " badlands " (see Figs. 19, 21). The thickness at any one place varies from a few hundred feet to several thousand, but if all the thickest local deposits are combined the total Cenozoic sedimentation attains to well over 20,000 feet. It is in this vast mass of material that lies buried the most interesting known record of mammalian evolution, the remains of one organic dynasty after another, whose histories have attracted the attention of paleontologists the world over.

Green River lake of Middle Eocene time, covering at least 350 by 150 miles of southwestern Wyoming, was shallow and lay near sea-level. Many of its deposits are bluish black in color and abound in petroleum that will some day be distilled from them. From these deposits have been described thirty-five fishes, among which are eight kinds that are clearly of the sea, showing that they got into this lake to spawn by migrating up some unknown river. One of them is a sting-ray.

The older geologists stated that these Cenozoic fresh-water strata had in the main been laid down in lakes of vast extent. During the

past twenty years, however, it has been shown that they are the materials of rivers originating in the mountains, and meandering and unloading over great flood plains under a more or less semiarid climate. In addition there is also a great deal of wind-borne material, desert dust and fine volcanic ashes from the western volcanoes, that at times killed and buried the flora and fauna over considerable areas.

Cascadian Revolution

In the chapter on the Cretaceous it was stated that the Mesozoic era in North America was closed by the Laramide Revolution, when the Laramide mountains (including the Rocky Mountains) were folded and thrust toward the east (see p. 612). Eruptions, mainly of an explosive character, continued, though with diminishing force, throughout Eocene and Oligocene time, but the earth-shell remained fairly stable, enabling the atmospheric forces to reduce greatly the high elevations of these mountains.

The crustal movements which attained their culmination at the close of the Cenozoic era, and which have been called the Cascadian Revolution, had their beginning as early as Middle Miocene time, when the Pacific States were again in the throes of mountain making, and igneous eruptions became active, with the formation of highlands in eastern Washington and Oregon. At the same time came the second period of elevation of the Coast Range of California. It is interesting to note here that the great San Andreas earthquake rift of California, which extends for 600 miles southeast into the Mohave desert, had its origin at this time.

At the close of the Pliocene or early in the Pleistocene, the Sierra Nevada was elevated bodily from 5000 to 7000 feet and it is still going up. These mountains form a crust block 300 miles long and 50 to 60 miles wide, greatly elevated on the eastern side, where there is a great fault with from 3 to 4 miles of vertical displacement.

During the Miocene, decided folding and faulting with volcanic activity also occurred in the Isthmus of Tehuantepec of southern Mexico, in Central America, and apparently throughout the West Indian islands. Finally, it may be said that especially during the Miocene, and less in the Pliocene, the entire area of the overlaps of the Pacific Ocean in North America (see Fig. 376) was being elevated, folded, faulted and thrust into the Pacific System of mountains. During the later Pliocene, the entire area of the Rocky Mountains, and especially the plateau region of the Colorado River, were further vertically elevated several thousand feet.

Eastern North America was also elevated at this time, but how much is not yet determined, and the entire Mississippi valley was raised several hundred feet, or to its present elevation.

The Cenozoic was a time of mountain making in other countries outside of the North American continent. In South America toward the close of the Cretaceous the Andes had been elevated, folded and thrust eastward throughout the length of the continent (4500 miles), and during most of Cenozoic time an extensive peneplain was being developed in the Central Andes. Vertical uplift began in later Cenozoic time, elevating this peneplain from 3000 to 7000 feet. This was in turn eroded to mature slopes and then reëlevated

Fig. 376. — Areas of dominant folding and uplift (oblique shading) during the Cenozoic. Horizontal shading, the fractured and down-sinking area of Eris; northwest-southeast lines, the general direction of fractures and dikes.

in Pliocene and early Pleistocene time, so that now the deeply dissected erosion surface of the old peneplain stands at an average elevation of 12,000 feet, though locally it varies between 6000 and 15,000 feet. This plain is the Altaplanici, the high plains of Bolivia. Upon it in the west rest immense lava flows and lofty volcanic cones, some of which attain a height of 21,000 feet above the sea.

Eastern Greenland and the region eastward across Spitzbergen, Norway, Sweden and Finland (Fennoscandia) were subject to great block faultings and warpings, seemingly in late Miocene time. This was the time when Eris was broken through, separating Laurentis from Baltis (Fig. 376). Periodically, but more especially during the

late Eocene and Oligocene, lava (the Thulean basalts) flowed widely through fissures over all the lands bordering the Atlantic in the northeast. The foundering of the crust where the Norwegian sea now is, permitted the triumphant spread of the Atlantic into the Arctic Ocean.

In Europe, the majestic Alps are mute evidence of the great unrest of the earth's crust during the Cenozoic. The movement here began in the west with the Pyrenees of Spain, the Rif Mountains of Morocco, and the Apennines of northern Italy. Then the entire Alpine system of western Europe began to rise, and this deformation was completed early in the Lower Pliocene, when these mountains stood at their highest.

The Himalayas of India, as early as the Middle Cretaceous, began blotting out in Asia much of the former extent of Tethys. At the close of the Eocene, however, all of the Tethyian area of the Himalayas and Burma began to fold, giving rise to mountains of considerable altitude in many regions, and yet not extensive enough to blot out the sea. During the Oligocene, Tethys, even though shallow, still preserved its continuity, but toward the close of the Middle Miocene, the second and more marked phase of folding began, changing it into a series of disconnected but subsiding basins. Finally, in the Pliocene, came the third and greatest upheaval, when the Himalayas, the loftiest mountains of the earth, were completed. This uplift affected the land to the north for 1400 miles into Tibet and Mongolia.

The closing revolution of the Cenozoic era was a critical period in the history of the earth, and as it culminated in the Pleistocene glacial climate, the conditions were all the more hazardous for the organisms that inhabited the polar and temperate parts of the earth. The warmer regions of the globe were the asylums that repeopled the northern lands, but man, probably arising in Asia even before the Pleistocene, advanced during the Glacial Period from the savage to the civilized state under the influence of cooler and even cold climates. We are now living in a time of rugged lands, obliteration of ancient peneplains, cold polar climates, and marked temperature belts.

Cenozoic Climate

In the area of the Rocky Mountains, the climate toward the close of the Cretaceous was as warm as at present along the Gulf of Mexico. Later, the temperature was cooler, with distinct winters like those of the present Dismal Swamp of Virginia; and during early Eocene time the climate was cool and semiarid.

Beds of tillites ranging in thickness from 80 to 100 feet were discovered in 1913 at a number of localities in the San Juan Mountains of Colorado. These tillites unconformably overlie the Cretaceous and are covered by Eocene tuffs, indicating a probable early Eocene age. It is to be expected that other areas of these tills will be found, in which event we may infer that the Laramide mountains were then widely covered by alpine and piedmont glaciers. Moreover, the early Eocene shales of Green River age are banded, and this strongly suggests seasonal deposition. Toward the close of the Eocene, however, the floras of even arctic lands show the return of mild climates, as mild as that of the present Gulf States. Along the Yukon then lived cycads, magnolias, firs and delicate ferns.

It has long been recognized that during all of the Oligocene there were world-wide genial climates. Furthermore, up to the close of the Oligocene the climates of North America were moist and the lands lay near sea-level. With the Miocene, however, the lands in many parts of the world began to rise into mountains, and gradually the climates became cooler and drier. More or less of desert climates developed in the Cordilleran areas of North America and have prevailed there ever since. In the Miocene, parts of Eris foundered, separating Greenland from Norway and Scotland, and colder waters spread all along the Atlantic shores of North America. The climate continued to grow cooler, and in the Pleistocene occurred one of the two most marked glacial climates known to geologists, described in Chapter XL.

Fig. 377. — Restoration of a giant bird of Miocene time found in Patagonia (*Phororhacos*). The skull is as large as that of the largest horse. From Lucas' *Animals of the Past.*

Life of the Cenozoic

The Mesozoic was the Age of Reptiles, the Cenozoic the Age of Mammals. The wonderful reptile development of the Mesozoic was nearly all gone in the earliest Eocene, and at no time in the Cenozoic or since have these animals played a conspicuous rôle. Their places were taken by the mammals, which were present in greatest variety and number and dominated the life not only of the

lands but of the seas and oceans as well. In the later Eocene occurred the first mammal adaptation to an oceanic life, in the form of whale-like animals (*Zeuglodon*). In the Oligocene came the sea-cows, and

Fig. 378. — Miocene tree trunks of the Fossil Forest, Yellowstone Park, Wyoming. Photograph by J. P. Iddings, U. S. Geol. Surv.

in the Miocene the true whales, seals and sea-lions. The land mammals are discussed in the following chapters.

Nearly all the continents at some time during the Cenozoic had large ground-living ostrich-like birds. The tallest and heaviest of these were the moas of New Zealand, exterminated by the Maoris

five or six centuries ago. There were about twenty kinds, the largest of which, *Dinornis maximus,* stood 10 feet high, 2 feet above the largest ostrich. Another closely related but smaller form was *Æpyornis* of Madagascar, a bird that laid the largest of all known eggs, 9 by 13 inches. It was the finding of these eggs by the early navigators that led to the vast exaggerations which thrill the reader with wonder and terror in the accounts of the Roc given by Sindbad the Sailor in the Arabian Nights.

During early Eocene time there lived in Wyoming a gigantic running bird with only vestiges of wings, known as *Diatryma.* A specimen of this mounted in the American Museum of Natural History stands nearly 7 feet high, and shows a short but massive neck surmounted by a head as large as that of a horse. The most powerful of all ground-living birds of Cenozoic time, however, was *Phororhacos,* found in the Pampas formation of Argentina, standing 7 to 8 feet, with a skull 23 inches long, heavy and decidedly beaked, apparently the most terrible of birds of prey. It was not at all related to the ostriches, but rather to the living herons (see Fig. 377).

The land floras of the Cenozoic had arisen in the Cretaceous, and the woody trees and bushes were much like those of the present (Fig. 378). The grasses and cereals, originating late in the Cretaceous, did not, however, take full possession of the open places until Miocene time, but with their coming began the greater evolution of the herbivorous animals.

CHAPTER XXXVIII

THE EVOLUTION OF MAMMALS AND THE RISE OF MENTALITY IN THE CENOZOIC

Mammals, structurally the highest group of animals, are warm-blooded vertebrates with milk glands. These glands, which vary in number from one to eleven pairs, are the mammary glands or breasts, the structures from which the class has taken its name, for *mamma* means *breast*. All mammals are more or less covered with hair, which is as characteristic of them as feathers are of birds. The body cavity differs from that of all other vertebrates in that it is completely divided into two parts by a muscular membrane, the diaphragm, which separates it into a thoracic cavity containing the heart and lungs, and an abdominal cavity containing the remaining viscera. In most mammals there are two sets of teeth, the milk dentition or temporary teeth which eventually fall out, and the permanent teeth which succeed them. The heart is four-chambered as in the other class of warm-blooded animals, the birds, and the course of the blood through it is the same in both.

The brain in mammals attains the highest degree of development known, reaching its greatest perfection in man. In the Mesozoic mammals the brain was always relatively undeveloped in comparison with that of modernized mammals of equivalent bulk, especially in the part wherein the intelligence lay, the upper brain or cerebrum. It was in the Eocene that the brain in most mammals began to enlarge, so that here it was about one-eighth that of living forms of the same stocks, and this enlargement was by far the most striking in the upper lobes. The Cenozoic was, in fact, the time of transition from an ignorant world of brutes to the present Age of Reason, the Psychozoic era.

Most mammals have a completely terrestrial habitat, while the seals, sea-lions, sea-cows, whales and porpoises, live in the oceans. One order of wide distribution, the bats, has developed the front limbs into wings, while other stocks have lateral or body membranes between the limbs, and spreading these, glide from tree to tree.

The Cenozoic of North America opens with an archaic indigenous mammal fauna, a most curious, strange and bizarre assemblage.

It is plain that it is an advanced and diversified fauna, the descendants of Mesozoic mammals. Later appear unheralded as migrants the modern types, and their introduction sounds the death knell of the archaic forms, for one stock after another vanishes and most of them are gone before the close of the Oligocene.

On earlier pages it was pointed out that the mammals originated in the theriodont reptiles of Africa (p. 576), and that in the Triassic of Europe and Virginia are found the very rare remains of the oldest known mammals (p. 587). These are small reptilian mammals of the stock known as Multituberculata. They developed from eggs and left as living descendants the small monotremes of Australia. In the later Jurassic, jaws of egg-laying mammals are more common, and it was about this time that some of the forms became viviparous, giving birth to more or less developed young. The group in which the young are more or less imperfectly developed are the marsupials (kangaroo of Australia), while the great horde of living and fossil mammals belong to the group Placentalia, the placenta being a special growth, partly of fœtal and partly of maternal origin, in which the young during the period of gestation are developed to greater perfection.

Archaic Mammals. — The North American late Cretaceous mammals were still very primitive, generalized, omnivorous or fruit-eating, dominantly placental and small. Already highly varied, in at least six orders, none of them were as large as a sheep, the limbs were short, with five digits each, the tails were long and heavy, and the brains extremely small. (See Fig. 379, of a much later archaic mammal.)

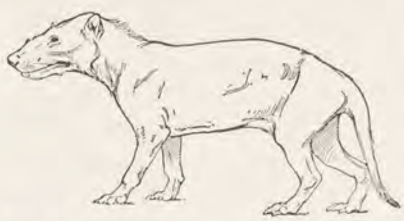

Fig. 379. — Restoration of the last of the archaic carnivores (*Hyænodon*), of Oligocene age. These animals were the direct ancestors of all later carnivores. From Osborn's *Age of Mammals* (Macmillan).

Eocene Mammals. — The most striking feature of the life of early Eocene time (Wasatch-Wind River) was the appearance in considerable numbers, both in western Europe and North America, of the progressive or modernized placental mammals. Where they came from is unknown, but it is established that there was free migration between North America, Europe and Asia, during early Eocene time.

Among these Lower Eocene mammals were diminutive horse-like forms (*Eohippus*, Fig. 380), fleet-footed rhinoceroses, tapirs without a proboscis, the first ruminants and pig-like forms, squirrel-like

rodents, carnivores, lemurs, monkeys and probably also marsupial opossums. It was in the main the mammalian life of a mountainous country, superior in foot and tooth structure to the indigenous archaic fauna and of a higher intelligence. In the struggle for existence the primitive mammals were consequently the losers.

In the great abundance of mammals in the later Eocene there was no evidence of new migrants having come from Asia or Europe, but the fauna was dominantly that of the older Eocene with a smaller proportion of archaic types. The changes were largely toward

Fig. 380. — The "dawn horse" (*Eohippus*) of the Lower Eocene. Restored from a skeleton in the American Museum of Natural History. From Scott's *History of Land Mammals* (Macmillan).

greater size, more muscular power, and the origination of new native forms. There were many hoofed animals and all were browsers. This was again an upland or mountainous mammal assemblage, on the whole well balanced, with an equal distribution of arboreal, running, aquatic, burrowing, carnivorous and herbivorous types.

Oligocene Mammals. — It was during the Oligocene that mammals for the first time took on a modern aspect, for here nearly all were progressive forms, and we begin to get representatives also of still existing families. Then in this period we get our first knowledge of the varied mammalian life of the open plains, the grazing

types, indicating that the grasses were taking possession of the open country.

Early in the Oligocene took place a second and more marked invasion from Europe. The interchange was considerable, yet it was not complete and the time of migration was of short duration. Europe lost its horses early in the Oligocene, but in North America there was continued evolution of the three-toed forms. The camels were also better represented, and among them were grazers, these and other hoofed mammals (see Fig. 381) being present in bewildering variety. The tapirs were not common, but of rhinoceroses there were many. Rodents were also common, such as beavers, squirrels, pocket gophers, mice and hares. Among the ruminants, peccaries were numerous, the entelodonts of large size (see Fig. 381), and the oreodonts, not unlike the peccaries and wild boars in appearance and size, ran in great herds (see Fig. 382). Among the carnivores, small dogs were remarkably abundant and diversified, in fact, more so than ever before or since.

Fig. 381. — One of the giant pigs or entelodonts (*Archæotherium*) of the Oligocene (White River). From Scott's *History of Land Mammals* (Macmillan)

Miocene Mammals. — The Miocene was the "Mammalian Golden Age" and the epoch is replete with interest because of the changes wrought in the faunas and in the floras by the alteration in climate to cooler and semiarid conditions. The later Miocene especially was characterized by an increase of grassy plains, and the mammalian teeth altered accordingly from those of the browsing type to the grinding or grazing kinds (Fig. 383). There were now large numbers of horses, camels, ruminants and rodents with high-crowned, persistently growing, grinding teeth.

The third marked migration of mammals into North America took place not only during the Miocene but during the Pliocene as well, and the migrants came from Asia by way of the Siberia-Alaska bridge. The most conspicuous among Miocene forms were the four-tusked, browsing, long-faced mastodons, the short-legged rhinoceroses, the cats and the beavers.

Prominent among the Miocene mammals were the horses, which roamed the plains in great herds. Camels were also plentiful. Rhinoceroses were present in great variety. Peccaries abounded, and the last of the giant pigs, the entelodonts, occurred in the Lower

Miocene, one of them being over 6 feet tall. Oreodonts were still present, but on the wane (see Fig. 382). The first of the true deer appeared in the Lower Miocene, and in addition there were hornless deer and antlered deer-antelopes that were slender and graceful little creatures.

Among the carnivores, the dog kinds were in great variety, some small, others as large as the largest bears. True cats appeared here

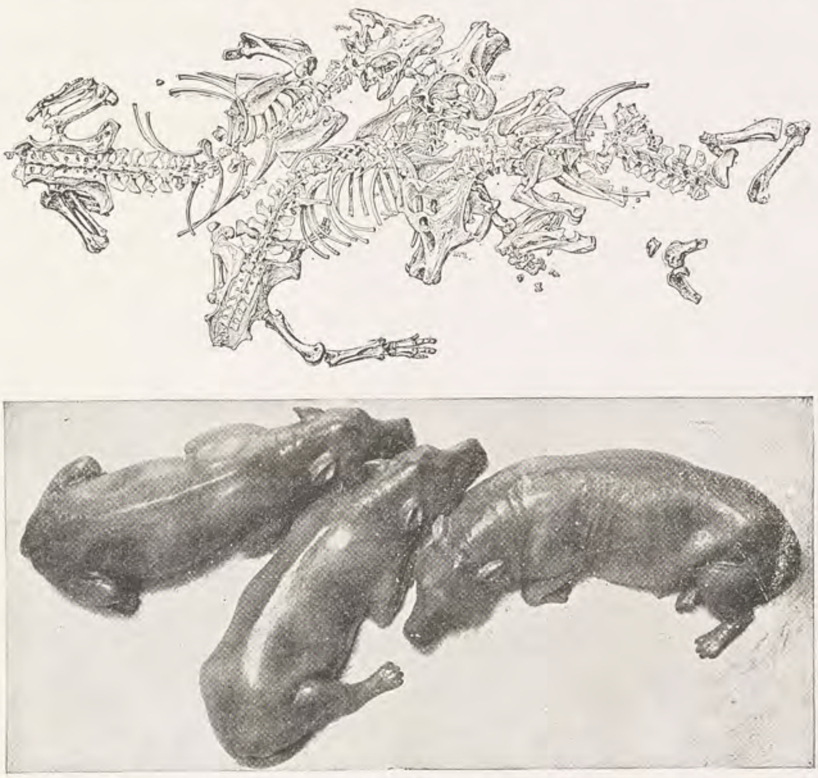

Fig. 382. — A remarkable group of three Miocene oreodonts (*Promerycochœrus carrikeri*). Above are the skeletons as found in the rocks (note how they are huddled together, having met death in this attitude), and below, the animals restored in the flesh. Found by O. A. Peterson in Sioux County, Nebraska. Original in the Carnegie Museum, Pittsburgh, Pennsylvania.

for the first time, and the sabre-tooth tigers (Fig. 390) were plentiful though not large. There were also weasels, martens, otters and raccoons, but no true bears are known in America before the Pleistocene.

Pliocene and Pleistocene Mammals. — Of Pliocene mammals in North America not much can be said, because strata of this age are scarce The continent stood high and was undergoing elevation

in the western portion, with the result that the rivers carried into the sea their loads of sand and mud.

Of mastodons there were several species; the horses, in considerable variety, were still three-toed; llamas and the tallest of giraffe-like camels continued to live; rhinoceroses with and without horns were present; sabre-tooth tigers and true cats existed, some of them as large as the lion.

Migration between North and South America took place very early in the Cenozoic, and the latter continent then for a long time evolved mammals peculiar to it. Probably the most striking of these were the huge Pleistocene ground sloths and the highly armored glyptodonts related to the armadillos (Fig. 391) and looking like great land tortoises. Both of these stocks migrated into the southern United States and are found there in Pleistocene strata.

Euro-Asiatic connection with North America is indicated by the migration of American camels into China and India during the Pliocene. At the same time the hollow- and twisted-horned antelopes came into America, along with the short-faced bears (arctotheres), now known in Oregon, Mexico and South America. The true bears arrived from Asia during the Pleistocene.

In late Pliocene time the mammals attained their climax of development, and this continued into the Pleistocene. Here also was the time of their greatest wandering, since the proboscideans, horses and camels were world-wide in their distribution. Then came the Ice Age and the ascendency of man, and one after another the magnificent mammals vanished. To get a picture of this climacteric late Pliocene mammal assemblage we must go to the tablelands of Africa, but here too it is doomed soon to disappear through the advent of the white man.

CHAPTER XXXIX

THE EVOLUTION OF HORSES, ELEPHANTS AND OTHER HOOFED MAMMALS

The Horses

In demonstrating the truth of evolution, the horses, above all organisms, are the best illustration of the working out of this doctrine. They are the "show animals" of evolution, since their history running back through millions of years is now well known, and nowhere is this history so complete as in the Cenozoic formations of the Great Plains of the United States.

The horse is the most useful and beautiful of man's domesticated animals, and has been one of the greatest factors in his civilization. In the early history of man, the horse served him as food, and later it became his chief means of travel and his beast of burden in agriculture and warfare. The horse is also among the most perfect and swiftest of organic running machines, as man loves to demonstrate in the race horse. As migrants into all continents, and in adapting themselves to varied environments — from torrid to arctic climes — horses have had but two equals — elephants and man.

The horse family (Equidæ, from *Equus caballus*, the domestic horse) includes the living horses, zebras and asses. They are characterized by very long and slender feet, each composed of but a single functional toe, the third digit. The hoof is the equivalent of the nail or claw of the third finger or toe in other animals; horses, therefore, walk upon the very tip of the third finger nail. As the third toe in each limb supports the entire horse, it is necessarily much larger than in animals in which the weight is distributed among several digits. There is, however, on each side of the functional digit, i.e., the "cannon-bone," a slender element known as the "splint bone." These are the vestiges of the second and fourth toes of the original five in the ancestors of horses (Fig. 383).

The teeth of horses are as peculiar to them as are their one-toed feet. The molars are long, square prisms which grow up from the gums as fast as they wear off on the crowns. The grinding surface exhibits a peculiar and complicated pattern of edges of hard enamel,

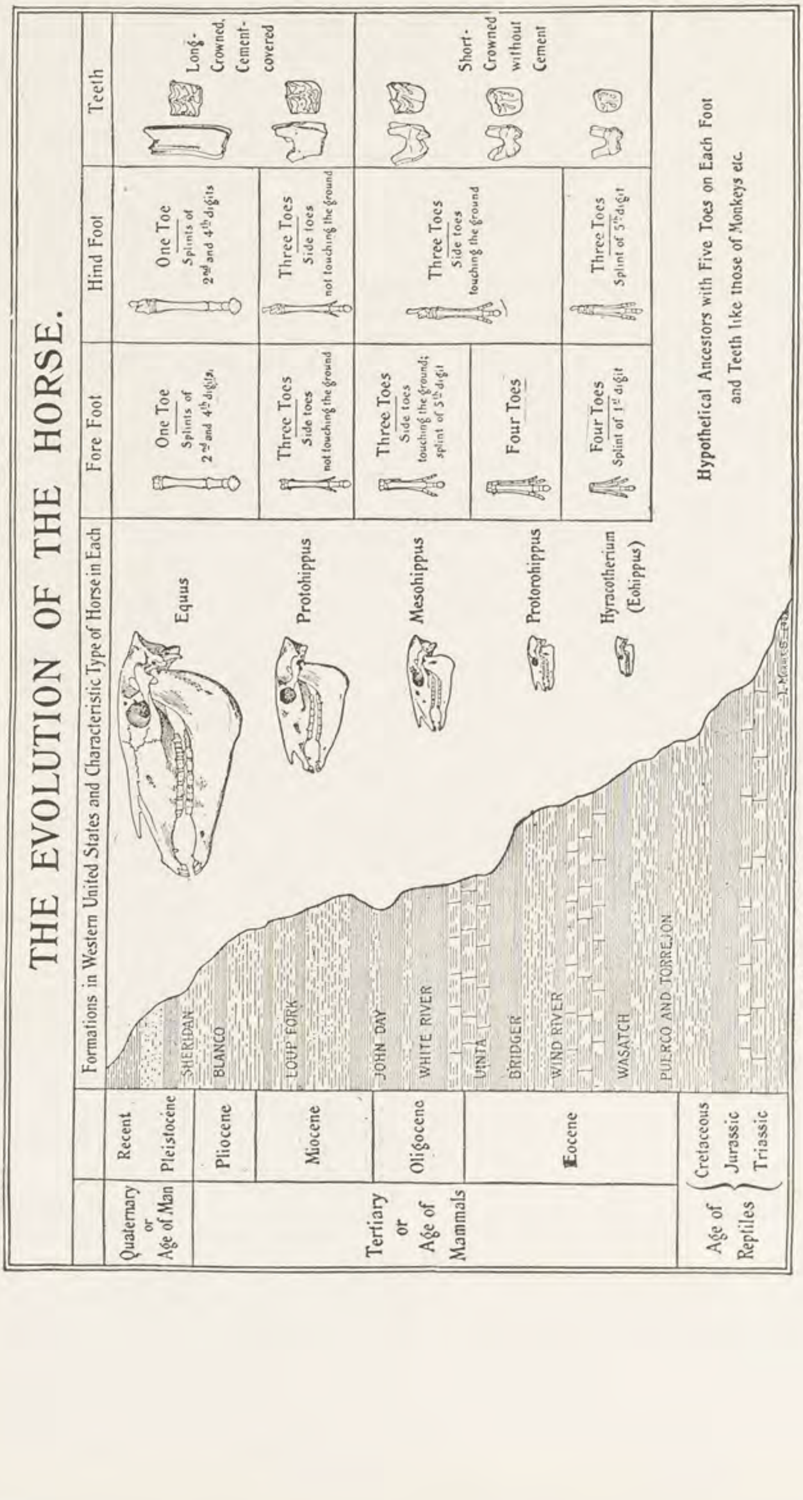

Fig. 383. — Diagram showing the evolution of the horse. After Osborn.

between which are softer spaces composed of dentine and of a material called cement.

Evolution (see Fig. 383). — The horse family has been traced back to near the beginning of the Cenozoic without a single important break. When the little four-toed "dawn horses" (*Eohippus*, Fig. 380), no larger than a small dog, appeared in western North America early in the Eocene, the land stood far nearer sea-level than it does now, and the climate, though at first with winters, soon became warm and equable throughout the year. Then for a long time the seasons were very much alike and the climate tropical and moist enough to induce extensive areas of forests, at least over the Cordilleras. Over the Great Plains, however, the climate was drier and here were great grassy open plains. With the Miocene the climate became cooler, drier and eventually icy cold. To all of these changes in the environment the horses adapted themselves or migrated into more favorable habitats, and in so doing changed from the smaller many-toed forms to the larger, fewer-toed, swifter and more intelligent ones.

At first the many-toed horses browsed in the forests, where they were an easy prey to the carnivores of the time, but with the diminishing of the forests and the appearance of the drier grassy plains, they spread for protection into the open plains, and here they developed more and more speed. With the elongation of the lower part of the limbs and the development of the sprinting habit of getting quickly up on the toes, came the gradual loss, through disuse, of the additional toes, and an equally remarkable change in teeth, from the browsing to the grazing type.

The brain of living horses is large and richly convoluted, implying a high intelligence, but it is not equal to that of the elephant. The docility of the horse and its ability to learn are notable. On the other hand, it is emotional, and its psychology is largely linked up with its normal mode of defense — flight. In the wild state this impulse toward flight is of the greatest possible aid as a means of survival.

Where the horse family first originated is not known. The "dawn horses" appeared at about the same time, and in the same state of evolution, in western Europe and North America. In Europe they soon died out (Eocene) but North America throughout the Cenozoic was their generating center. Curiously, however, even though horses were present throughout the Pleistocene in both North and South America, they had all died out at some time before the advent of the red men. Our present wild horses are feral, that is, had

domesticated ancestors, and those of Asia, Africa and Europe are the descendants of early Miocene horses that spread from North America to Siberia by way of Alaska.

The Giant-beasts or Titanotheres

In the Lower Eocene, among the immigrant modernized mammals there appeared an odd-toed hoofed animal (*Eotitanops*, Fig. 384), smaller than a sheep and in appearance suggestive of a tapir. This ancestral form evolved into eleven principal branches, the deployment beginning in the Middle Eocene and vanishing at the climax of its development in early Oligocene time. Late in the Eocene the group spread into Mongolia (*Protitanotherium*), but apparently did not live there long.

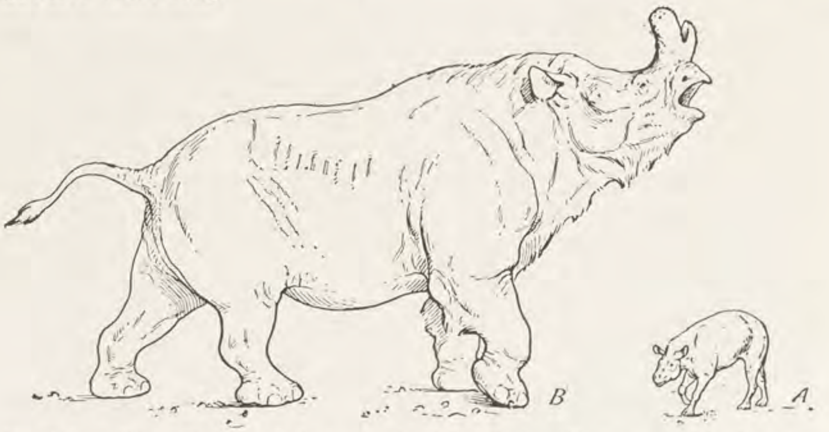

Fig. 384. — Titanotheres. *A*, first stage in the evolution (*Eotitanops* of the Eocene). *B*, last known stage (*Brontotherium* of the Oligocene). After Osborn.

These titanotheres, or "giant-beasts," were very characteristic of the North American Cenozoic, but are now completely extinct. Only the later forms attained the size of small elephants, but *Brontotherium* was one of the most imposing products of mammalian evolution (see Fig. 384). Why these mighty animals failed to survive is not known, but it may be that the drier climatic conditions of the Miocene and the changing of their forest habitats to open grass lands proved their undoing.

The titanotheres were heavy in body, with columnar legs and short feet, the latter supported on thick pads as in elephants. In all of them the front feet had four toes and the hind three, and in the older and smaller forms the toes and hoofs were more prominent. Their most characteristic single feature, however, lay in the evolu-

tion of the head. In the older ones the skull was small, long and narrow, and devoid of knobs, but in the late Eocene the animals were larger and had small knobs over the eyes that with time steadily enlarged and shifted forward, until in the early Oligocene these bony horns had attained great size and were situated on the nose.

The Rhinoceroses

The rhinoceroses are generally three-toed, and typically thick-skinned; as a rule, they have but little hair. They are browsers and grazers and live in forests, steppes and marshes. The living forms

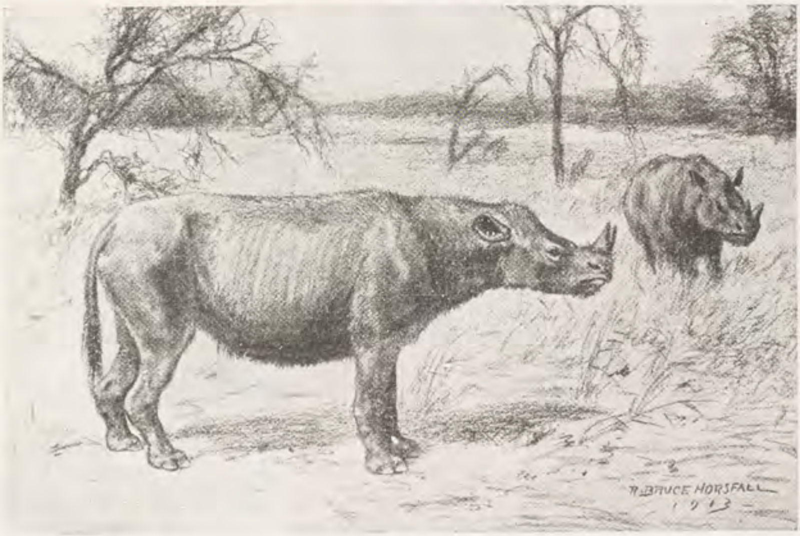

Fig. 385. — The small pair-horned rhinoceros (*Diceratherium cooki*) of the Lower Miocene of Nebraska. From Scott's *History of Land Mammals* (Macmillan).

stand from 4 feet to $6\frac{1}{2}$ feet tall at the shoulders. The horns of rhinoceroses are peculiar in that they are neither hollow as in cattle, nor of bone, but are solid dermal growths made up of agglutinated hairs, and for this reason are never found fossil.

Since Middle Pliocene time there have been no rhinoceroses in North America, and yet this continent may have been not only the place of their origin, but that of their most significant evolution as well. The origin and development of the ancestral forms in North America and later of the true rhinoceroses of the Old World is a very complex history, much more so than that of the horses and titanotheres. Rhinoceros-like mammals appeared in America early in the

Eocene in small, active and generalized forms (*Hyrachyus*) that in the course of the Cenozoic deployed into at least eight branches. In Miocene and Pliocene times, these animals had their widest distribution, living then in all continents except Australia and South America (see Fig. 385). In our own continent there were at least four distinct types of them living in great abundance in the Upper Miocene and Lower Pliocene, but none of them attained the size or bore the great horns of the living species.

The Elephants

Among the mammals of the Cenozoic, there was no group more spectacular in its evolution and distribution than the bulky trunk-bearing elephant stock, and among present-day land animals they still lead in size, strangeness of form and bulk of brain (Fig. 386). Of living elephants there are, however, but two kinds, the larger, big-eared ones of Africa, some of which attain a weight of about 8 tons and a height of 13 feet at the shoulders, and the somewhat less heavy and smaller-eared type found in India and central Asia.

Elephant-like mammals are technically known as Proboscidea, the proboscis being the trunk which is their most characteristic feature. This is in reality the greatly elongated nose, nostrils and upper lip, forming a very flexible and powerful muscular adjunct to the head, and serving many purposes but used chiefly in gathering food and water and conveying them to the mouth far above the ground.

The head of elephants is not only large, but is peculiar also in its great height as compared to its width; in other words, it is bulldog-like. The height of the skull is an adaptation to give greater muscular area, and, therefore, stronger leverage for the neck muscles which support the head and trunk. The upper part of the skull is, however, decidedly cellular. The greater transfiguration of the proboscideans took place in the head and in the trunk (see Fig. 386), beginning in long-headed forms with very short trunks and progressing steadily into the present high type of skull with long trunk.

In the Pleistocene, the distribution of the elephants was nearly world-wide and in all climates, even the very cold ones of Siberia and Alaska north to the Arctic Ocean (woolly mammoth, *Elephas primigenius*, see Fig. 387, *C*). The earliest known proboscidean-like animals are found in the late Eocene and Oligocene of Egypt (*Mœritherium*, Fig. 386). The more primitive forms are thought to have been stream and lake dwellers, that is, amphibious in habit, and not

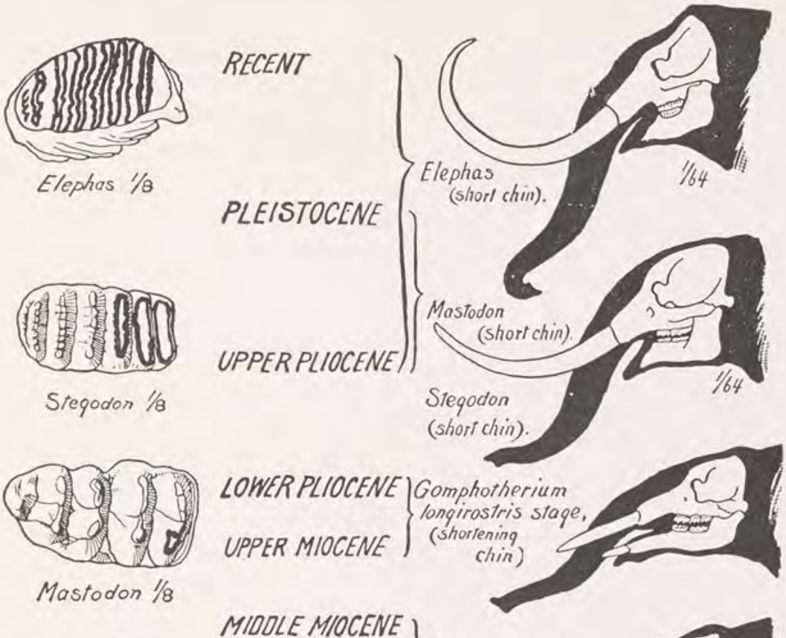

Fig. 386. — Evolution of the Proboscidea. On the right, a series of skulls with the flesh restored in silhouette. On the left, last lower molars. After Lull, from Scott's *History of Land Mammals* (Macmillan).

until the group took to the forests and grassy plains did their distribution become so general.

Evolution. — *Palæomastodon* (see Fig. 386) of the Lower Oligocene of Egypt, the oldest undoubted proboscidean, was about the size of a tapir, with a narrow face and a well developed, flexible snout rather than a trunk. The tusks of the skull were short, compressed and outwardly directed; those of the jaws, while larger, pointed straight forward. These tusks originated in the second incisors, the other front teeth remaining small. All of the grinding teeth were

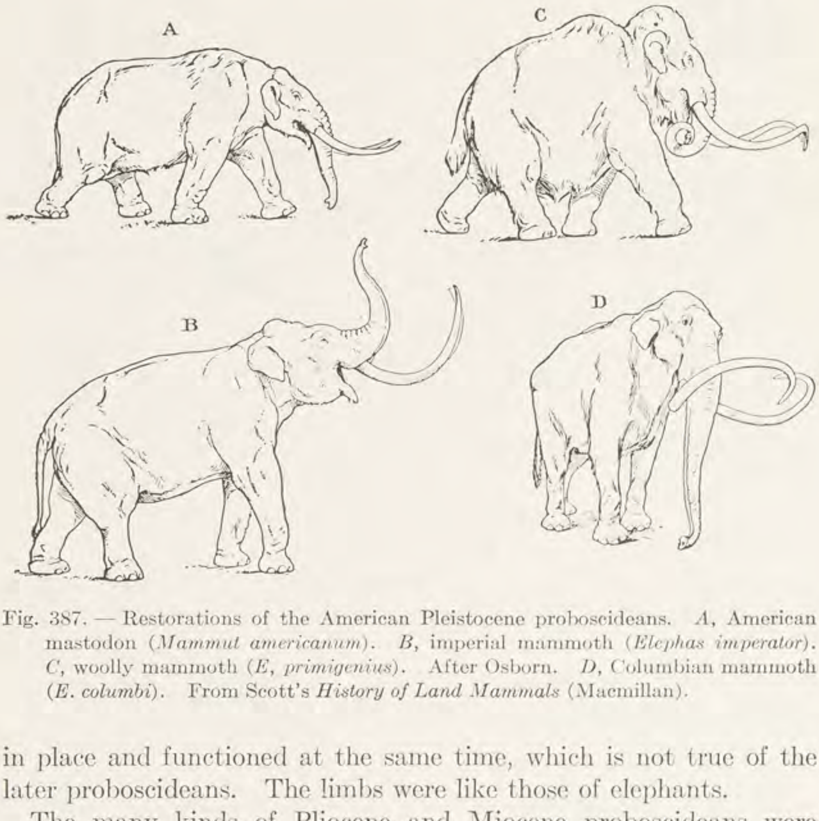

Fig. 387. — Restorations of the American Pleistocene proboscideans. *A*, American mastodon (*Mammut americanum*). *B*, imperial mammoth (*Elephas imperator*). *C*, woolly mammoth (*E, primigenius*). After Osborn. *D*, Columbian mammoth (*E. columbi*). From Scott's *History of Land Mammals* (Macmillan).

in place and functioned at the same time, which is not true of the later proboscideans. The limbs were like those of elephants.

The many kinds of Pliocene and Miocene proboscideans were smaller than those of the Pleistocene. Some were two-tusked (*Dibelodon*), and others were long-faced and had four tusks (*Tetralophodon, Trilophodon, Gomphotherium*, Fig. 386). It is out of the long-faced forms that has come the fullness of proboscidean development. In North America the best known form is the American mastodon (*Mammut americanum*, Fig. 387, *A*), skeletons of which are

found from Florida north into Alaska, from Connecticut to California, and from central Russia eastward throughout Siberia.

Of true elephants there were at least a dozen extinct species. Three of these occurred in the Pleistocene of North America, the woolly mammoth and the Columbian and Imperial elephants, all of which were very large. Of these, the mammoth (*Elephas primigenius*) is best known, and its distribution was very wide, not only in America, but in Europe and Asia as well. (See Fig. 387.)

Palæomastodon or its descendants, the long-faced forms, crossed from Africa by way of a land bridge through the Mediterranean from Tunis, Sicily and Italy to Eurasia. This bridge was in existence in Oligocene time. From here the deployment was both to the west into Great Britain, and possibly even to North America by way of an early Miocene land bridge connecting America and Europe across the Shetland Islands, Iceland and Greenland, and eastward across Asia and finally by way of Siberia as far as Nome in Alaska. Finally in the Pliocene the elephants spread from North into South America. Hence the proboscideans have been world-wide travellers, equalled only by the horses and exceeded only by man.

In western Europe there is excellent evidence that man was well acquainted with the woolly mammoth, since toward the close of the Pleistocene he engraved its picture on bone and ivory and painted it on the walls of caves (see Fig. 395).

CHAPTER XL

PLEISTOCENE TIME AND THE LAST GLACIAL CLIMATE

The Pleistocene, the final division of the Cenozoic era, and hence of geologic chronology, though brief as compared with the older divisions, was one of the critical times in the history of the earth. The distinguishing feature of this time was its very extensive glaciation; in fact, there appear to have been a series of glaciations, for ice-sheets covering about 8,000,000 square miles of the earth's surface existed at one time or another during the period in the temperate and colder regions of the two hemispheres (Fig. 388). This is all the more remarkable when we consider that the ice-sheets were mainly of the low lands, and that the climates for a very long time previous had been mild. All of the water of these ice-sheets had been taken from the oceans and precipitated as snow on the continents, the decrease of temperature being such that the snow-line (see p. 120) was lowered about 4000 feet below its present limit (Fig. 389), and the sea-level in the tropics lowered something like 400 feet.

The loading of the lands with so much ice caused the crust to subside in the areas of the ice-sheets, while the regions immediately outside of the latter were apparently somewhat upwarped. The surface of the glaciated lands, was, therefore, more or less unsteady, warping up and down some hundreds of feet in consonance with the changes going on in the ice-fields during Pleistocene time. In addition, broad crustal movements unrelated to the glaciation had been in progress during the Pliocene and continued at intervals in the Pleistocene. As a result of these combinations of several causes, the streams and shore-lines of the glaciated areas generally show at the present time the marks of extreme youth — sharp gorges, drowned channels, barrier beaches and elevated strand-lines.

The development of such immense ice-fields upon the lands and the attendant reduction of temperature also meant the blotting out of vast areas on which no life or at least but little could exist. The Pleistocene was, therefore, a critical time in the history of the earth, especially for the plant and animal life of the glaciated lands and the shallow-water life of the northern and southern oceans. The cold waters, pouring into the oceans, sank into the depths, and the con-

Fig. 388. — World map of Pleistocene glaciation. Carnegie Institution of Washington.

ditions there also became critical for the sparse life. In the shallow waters of the warm parts of the ocean, however, there was almost no change in the environment, and consequently there is recorded here almost nothing more than the usual evolutional faunal alterations.

The record of the areas where the ice-fields prevailed during this " Great Ice Age " consists in the main of a varied and most often a heterogeneous series of continental deposits, the Diluvium or Deluge material of the older philosophers, and the drift or tills of modern students of earth science. Characteristic of this drift are the included erratics, the bowlder beds known as tillites, the banded or varved clays or pellodites, and a striated or scoured ground. Soils are mostly yellowish and thin, or absent, and everywhere occur lakes of varying sizes occupying the ice-made basins.

Outside of the areas of glaciation the Pleistocene strata are in general like other continental formations laid down under moist and warmer climates, but the marine record is nearly everywhere very scanty.

There are wind deposits of sand and dust along the rivers and the shores of lakes, and in various arid areas occur accumulations of dust (loess); elsewhere there are sediments of rivers and lakes and the deposits made by springs, asphalt pools and fillings of caves and sinkholes often abounding in bones, peats and marls of marshes and ponds, lavas and ashes in the areas to the west of the Rocky Mountains, and finally the fresh-water, estuarine and marine accumulations along the borders of the continent. All of these deposits are apt to be thin and localized.

The glacial clays in many places in northern North America and Europe are regularly laminated, and De Geer of Sweden has demonstrated that this banding was due to seasonal changes. A darker (winter) and a lighter (summer) band are laid down each year, and each pair is called a varve. Counting these layers throughout Sweden, De Geer has determined that the ice-sheet began to leave the southern end of that country 12,000 years ago, and northern Germany about 17,000 years ago.

The Pleistocene was followed by the Recent, or present time, but how long this has been going on can not yet be stated. In a general way, we may say that the estimates vary between 20,000 and 50,000 years, with the probability that the smaller figure may be nearer the truth. As man has dominated the organic world since the beginning of the Recent, this is also known as Psychozoic time, or the Age of Mind.

General Distribution of Glaciation. — In the discussion of Pleistocene glaciation it should be recognized that the ice has only partly withdrawn, Greenland and Antarctica being still mantled with continental ice-sheets. It is the excess of glaciation beyond the present areas that is to be considered in the discussion of the wide distribution of the ice-fields of the Pleistocene.

More than half of the glaciated area during the Pleistocene was in North America, and more than half the remainder in Europe. The glaciation was, therefore, notably localized, though its effects were world-wide (Fig. 388). In North America it was mainly the northeastern half, and the plains country rather than the mountainous region, that was deeply buried under the continental glaciers (p. 124). Alaska was in the main free of ice and the same appears to have been true of the Arctic archipelago. There were three great centers of ice accumulation and radiation in North America, covering together an area of about 4,000,000 square miles. The *Keewatin ice-sheet* was the most extensive, covering the great medial flat area of the continent southward into Missouri and westward into the high plains to within 800 to 1000 miles of the Rocky Mountains. The *Labradorean ice-sheet* was not much smaller, and extended from northern Labrador southwestward for 1600 miles to the Ohio River. The main flow of the ice was southward toward the region of melting, marked by greater warmth. *Newfoundland* and *Nova Scotia* appear to have had independent ice-sheets, while *Greenland* was glaciated more extensively than now but not completely across Davis Strait so as to connect with the Labradorean mass. The *Cordilleran ice-sheet* covered all of the Cordilleran area from Alaska southward into Oregon, Idaho and Montana. Farther south there were local alpine glaciers in the Rocky Mountains, the Coast Ranges, and the Sierra Nevada of California.

How thick the Keewatin and Labradorean ice-sheets were is not known. It is widely held, however, that they must have been some thousands of feet in depth to have enabled them to flow southward with a descending grade across the higher irregularities. Geologists as a rule believe that the thickness at the centers of ice dispersion could not have been less than 4000 feet, and that it may have exceeded this average depth.

Alternating Cold and Warm Stages. — It is a well known fact that in most areas of past glaciation there occur, between sheets of drift, beds of peat and clays with fossil leaves and wood, and sands with bones of many kinds of large mammals. These fossils show clearly alternating groups of plants and animals living in different climates;

one set is of northern origin and of cold habitat, while the following one is from the south and of mild climes. The cold climate assemblages have among other forms reindeer, caribou, musk-oxen, moose, woolly mammoths (Fig. 387, *C*), and walrus, while those of the warm climates have lions, sabre-tooth tigers (Fig. 390), peccaries, tapirs, camels, llamas, many horses, hippopotamuses, great sloths (Fig. 391), the Columbian and Imperial elephants (Fig. 387, *B*, *D*), and the manatee or sea-cows. It is the succession of these fossils in the Pleistocene strata that has led to the discerning of alternating warm and cold climates, corresponding to the retreat and advance of the glaciers. These alterations led to very extensive migrations of

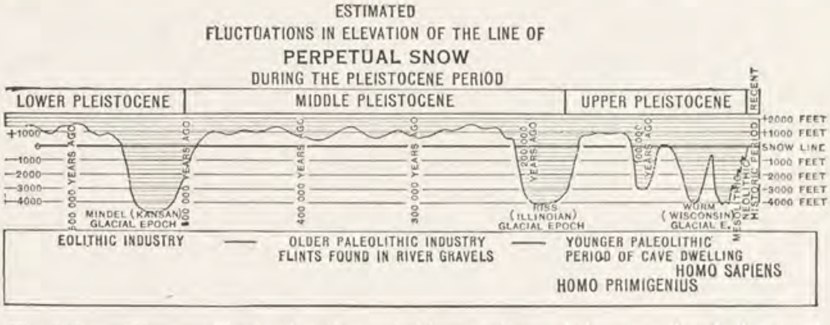

Fig. 389. — Diagram illustrating the probable variations of the snow-line during most of the Pleistocene and Recent, on the basis of a conservative time estimate stated in years. Drawn to scale. The succession of human events is also indicated. Prepared by Joseph Barrell.

mammals from one part of the continent to another, as the conditions of temperature and moisture changed. During the warm interglacial times, southern species spread far to the north, as when mastodon ranged into Alaska and the sea-cow spread north to New Jersey. Increasing cold and the spread of glaciation brought about a reverse migration and drove northern and even Arctic forms far to the south. Musk-oxen then spread into Utah and as far south as Oklahoma, Arkansas, Missouri, Ohio and Pennsylvania; the northern or woolly mammoth (Fig. 387, *C*) lived south of the Ohio and Potomac rivers, and the walrus had its home along the strands of New Jersey.

It has come to be generally held, therefore, that during the Pleistocene the temperature varied more than once between cold and warmer climates. During the cold times there was increase in the extent and thickness of the continental ice-sheets, and during the warmer interglacial stages the ice was melted away to a greater or

less degree. However, as to the number of these alternations there is as yet no unanimity among geologists, because of the great difficulties in correlating the separated areas of glacial material, all of which are so much alike. Some geologists recognize three, and others as many as six glacial stages, with from two to five interglacial warmer times (see Fig. 389).

It is now widely accepted that the interglacial times were markedly variable in duration and that all of them were not only warmer than the present, but that they lasted longer, and sometimes much longer, than the glacial stages. In Europe one of the interglacial times was so warm that the lion and the hippopotamus lived with man in England.

Effects of the Glaciation. — The geologic work done by glaciers in general is described on pages 138 to 144. Erosion by the continental ice-sheets was unequal and the deposition of the drift materials was especially irregular in distribution. From this it follows that the drainage system of the land was deranged and considerably modified. River valleys were locally filled by the drift to depths ranging up to 400 feet, or partially covered over by the ice, forcing the drainage around its front. In fact, the drainage of the glaciated areas was in certain regions revolutionized. The Ohio and the Missouri — the master streams of the United States marginal to the glaciated area — were built up from previous systems, and a host of their tributaries within the glaciated area suffered marked changes.

All ice-sheets push out lobes along the preëxisting valleys, and those of the Great Ice Age were no exception to this rule. Accordingly, the Keewatin ice-sheet, when it finally melted and retreated across the area of the Great Lakes, had lobes that extended along the ancient valleys (see Fig. 104), scouring them deeper, and leaving in front, as they receded, small lakes that grew to ever greater proportions. The first to appear were Lake Chicago, the beginning of Lake Michigan; Lake Saginaw, a part of the future Lake Huron; and Lake Whittlesey, which was of considerably larger extent than its descendant, Lake Erie. At this time, certain of the present small rivers were large, as the St. Croix, Wisconsin, Rock and Illinois, draining the vast melting waters of the Keewatin ice-field into the Mississippi River. In central New York the " finger lakes " were considerably larger than they are now and their waters for a long time drained into the Susquehanna River, and later through the Mohawk and Hudson rivers. Finally, when the ice had retreated well into Canada, all the Great Lakes were connected far more widely than they are now and drained out eastward through the Ottawa and

St. Lawrence valleys. It was this eastward drainage that originated Niagara Falls, which formerly began at Lewiston, New York. It is thought that the making of the gorge by the Niagara River from Lewiston to the present Falls has taken something like 10,000 years.

When the ice-sheets had finally retreated into Canada and across the St. Lawrence valley and Lake Ontario, the Atlantic Ocean found the glaciated lands depressed, and as a further result of the melting glaciers, the rising waters entered the depression and filled it at least 690 feet deeper than now. This was, therefore, a time of inland or epeiric seas, and it is certain that at some time in the Pleistocene Hudson Bay also appeared, since in the western part of the bay marine strata occur on the hillsides up to a height of 600 feet. In other words, a great part of eastern North America sank under the enormous load of the ice-sheet, and when the latter vanished, the rising Atlantic flooded deeply Hudson Bay, the St. Lawrence and Ottawa valleys, all of Lake Ontario and Lake Champlain, and southward to the east of Lake George. Marine shells and the bones of whales and seals are found about Lake Champlain at elevations of up to 440 feet above the present level of the water, at 520 feet near Montreal, and at 480 feet near Ottawa (see p. 80, under " relic lakes ").

At no time in the Pleistocene earlier than the St. Lawrence marine invasion just described is the continent known to have been invaded by the oceans to any great extent. The marine strand-line was not, however, a constant one during the Pleistocene, but oscillated up and down within some hundreds of feet, due to the subtraction of water as vapor from the oceans and the piling of it upon the continents in the solid form of snow and ice. Geologists have pointed out that when the great ice-sheet existed on the land, the oceanic level between 30° N. and 30° S. must have been depressed to a maximum of not more than 420 feet in the region of the equator, the amount of depression depending upon the mass of the continental ice-sheet. During the Pleistocene warm intervals, the ice of the lands was more or less completely melted away and the water returned to the oceans, thus raising the strand-line. When the ice began to accumulate on the lands, the oceanic level was depressed and the continents enlarged. At these times the lowered strand-lines everywhere began to cut more or less wide shelves or sea terraces into the lands, and when the waters returned it was upon these flooded shelves and those of the oceanic islands that the warm-water reef-corals began their making of the thick coral-reef limestones.

Causes of Glacial Climate. — As yet there is no accepted explanation of why the earth from time to time undergoes glacial climates, but it is becoming clearer that they are due rather to a combination of causes than to a single cause. Probably the greatest single factor is high altitude of the continents, with great chains of new mountains which disturb the general direction and constitution of the air currents. On the other hand, it must not be forgotten that when the lands are highly emergent, the formerly isolated lands are connected by land bridges that more or less alter the oceanic water circulation and therefore the local temperature.

Another possible factor is the variation in solar energy, since all of the appreciable heat of the atmosphere is derived from the sun. It is now well known that the sun is a slightly variable star, and a solar change of 5 per cent, continued for six months, might well alter the mean temperature of inland stations 3–6° F., which would make the difference between an unusually hot and an unusually cold season. Moreover, authorities on glaciation have concluded that if the mean temperature of the earth were to fall 9° or 11° F. and were to remain thus low for a sufficient length of time, meteorological conditions would be so altered that a large part of North America would be covered with ice down to about the fortieth degree of latitude, and Europe would suffer a corresponding glaciation.

Briefly, then, we may conclude that the markedly varying climates of the past seem to have been due in part to periodic changes in the sun, but mainly to alterations in the topographic form of the earth's surface, plus variations in the amount of heat stored by the oceans. The causation for the warmer interglacial climates may lie in oscillations of solar energy.

Life of the Pleistocene

The most interesting life of the Pleistocene is naturally the mammalian, and even though the remains of it are very fragmentary, they give a fair idea of its nature. The most striking of the Pleistocene mammals in North America were the three species of elephants and the one of mastodon. The last named, *Mammut americanum*, migrated from Siberia into Alaska, and ranged over nearly all of the United States and southern Canada (Fig. 387, *A*). It was most abundant in the forested regions and rarer in the plains country, and persisted so long that the animal may have been hunted to extermination by the red men.

Of the elephants, the most interesting and widely distributed was the Siberian woolly mammoth (*Elephas primigenius*), an animal of

the cold climate, standing about 9 feet tall at the shoulders, and coming to North America by way of Alaska (Fig. 387, *C*). It ranged from the far north through British Columbia into the United States and across to the Atlantic Coast. The mammoth also migrated from Asia into Europe and was there hunted by Pleistocene man (Fig. 395). It died out in North America late in Pleistocene time.

Closely related to the above form was the Columbian elephant (*Elephas columbi*), of taller stature, being 11 feet at the shoulders

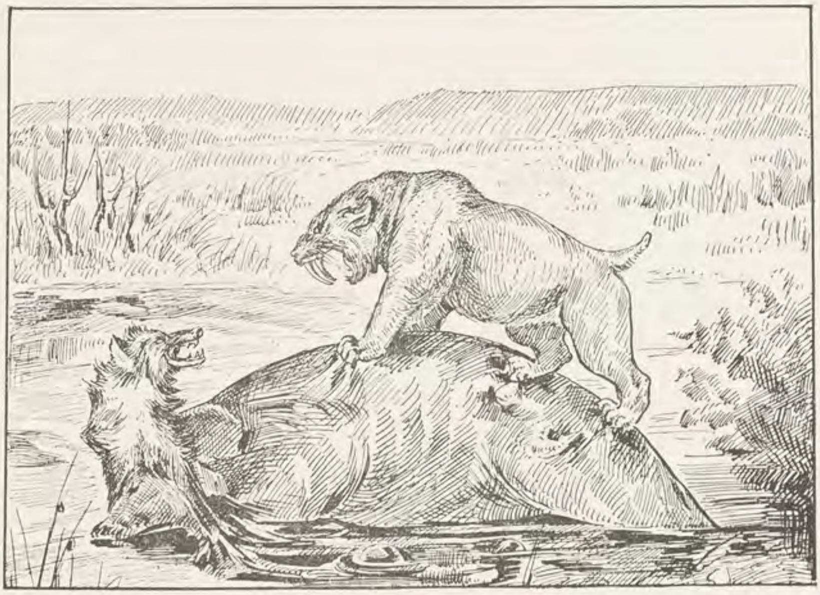

Fig. 390. — Restoration of the Pleistocene petroleum or asphalt pool at Rancho La Brea, near Los Angeles, California. The picture shows the sabre-tooth tiger (*Smilodon californicus*) standing on the carcass of an elephant (*Elephas columbi*) which has been trapped in the sticky asphalt, and snarling at a giant wolf (*Canis dirus*). Redrawn from the frontispiece of Scott's *History of Land Mammals in the Western Hemisphere* (Macmillan, 1913).

(Fig. 387, *D*). It lived during the earlier half of Pleistocene time in the warmer portions of North America, roaming over the whole United States and the high plains of Mexico. The third species was the huge Imperial elephant (*Elephas imperator*), said to have attained 13 feet 6 inches in height (Fig. 387, *B*). It was probably a plains animal that survived from Pliocene times and died out in the Middle Pleistocene. Its known range was western America from Nebraska to Mexico City.

Fig. 391. — Mammals of Pleistocene time but of the warmer southern climate. Giant sloth (*Megatherium*) and two kinds of glyptodonts (*Glyptodon* above, *Dædicurus* below), from the Pleistocene (Pampean) of Argentina. After J. Smit, from Knipe's *Nebula to Man.*

The horses were exceedingly numerous in the earlier Pleistocene, and roamed, apparently in great herds, all over Mexico and the United States and even into Alaska. There were at least ten species of *Equus*, one no larger than the smallest pony, others larger than the heaviest modern draft-horses. They were descendants of American Pliocene horses, and all died out during the Pleistocene.

Of peccaries there was an abundance, and there were also camels and llamas. During the times of glaciation the caribou ranged south into Pennsylvania and musk-oxen into Utah, Arkansas and Ohio. The modern moose was present in the western half of the continent, but the stag-moose (*Cervalces scotti*) was a late arrival during the last ice invasion. Other ruminants related to the musk-ox occurred earlier in the period, and of bison there were at least seven kinds, ranging from Florida to Alaska, one species, *Bison latifrons*, with a horn spread of 6 feet.

Among the carnivores, the most formidable was the great sabre-tooth tiger (*Smilodon*, see Fig. 390), which lived over the greater part of the United States. Of rodents the most interesting was the late Pleistocene giant beaver (*Castoroides ohioensis*), as large as a black bear.

The ground-sloths were represented by a large and widely spread form, *Megalonyx*, discovered and named by President Thomas Jefferson. The giant southern form, *Megatherium* (Fig. 391), had a body as large as that of an elephant, though shorter in limb, while the oldest and smallest of the sloths was *Mylodon*.

CHAPTER XLI

MAN'S PLACE IN NATURE

The title of this chapter is the same as that of one of Huxley's famous books, in which he states: " The question of questions for mankind — the problem which underlies all others, and is more deeply interesting than any other — is the ascertainment of the place which Man occupies in nature and of his relations to the universe of things." Some of us may not be inclined to study man as a part of nature, but whatever our prejudices, man's physical welfare and intellectual uplift into ever higher and higher states of civilization are unquestionably bound up with the ascertaining of his relations to the rest of nature. " Man is the paragon of animals, the climax of evolution " (Conklin).

Comparisons Between Man and the Other Primates. — Man seems to us so very different from all the animals that we can not believe him to be related to them at all, and prefer to regard him as standing isolated and alone, something quite apart from all other organisms. When, however, we begin to study his body and compare it, organ by organ, with that of other animals, we see that his isolation disappears, and that it is the thick veil of civilization in which he has so completely hidden himself that misleads us regarding his true position in the animal kingdom.

Linnæus (1707–1778), the founder of systematic Zoölogy, in his classification of animals placed man at the head of the highest group of vertebrates, the Primates (from the Latin *primus*, first). The most primitive Primates are the lemurs, and the higher ones are the anthropoids (means *man* and *form*), in which the brain is more highly developed than in any other animals. The latter division includes the monkeys, baboons, mandrills, macaques, gibbons, apes and man.

Structurally, man and the other anthropoids are very similar, the skeletal differences being due to man's more erect posture and his changed mode of living. The erect posture of man is of ancient origin, for it is fully developed in the oldest fossil men, and probably had its beginning in the gibbons of Pliocene time. It is not, however, so much in his posture that man differs from the other large anthropoids as in his manner of progression. The larger apes spend the

major portion of their time in the trees, and their strong fore limbs are especially adapted for swinging from branch to branch. Man, on the other hand, is adapted to living on the ground, "an adaptation which allowed him to escape beyond the limits of forests and occupy the whole world." This change of habitat resulted in a relative shortening of the fore limbs and a greater development of the legs, which now bore all the weight of the body. Moreover, since the human type of leg and foot is already present in the oldest known fossil man, it is clear that this evolution also took place prior to the Pleistocene. The human type of leg and foot was, then, developed long before the human brain came to be as we see it now. The large brain of man appears, in fact, to be his latest acquisition; his foot,

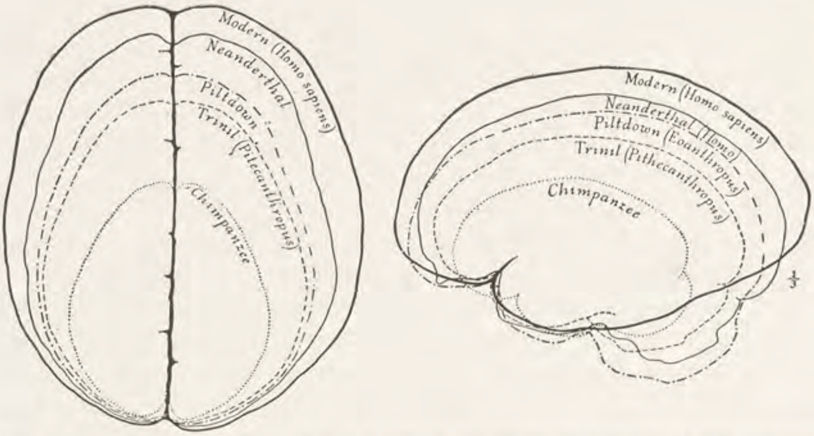

Fig. 392. — Diagrams from the top and side of the brains of chimpanzee and ancient and modern man, showing in outline their relative sizes and shapes. From Osborn's *Men of the Old Stone Age* (Scribner's, 1915).

leg and gait are older, his size of body older still, and his erect posture quite an ancient character.

The brain of the higher vertebrates consists of two main parts, a lower and hinder division known as the cerebellum, and an upper part, the cerebrum, that is again divided into right and left hemispheres (Fig. 392). In the mammals previous to the Oligocene the lower brain is the larger, but beginning with this time the upper brain, where reason and memory are located, increases rapidly in size in nearly all stocks and finally is considerably greater than the entire cerebellum, and almost covers it.

In man the size of the brain depends to a certain extent upon the bulk of the body; tall men on the average have larger brains

than small men. In adult men the weight of the brain varies between 65 and 34 ounces (average 49), and in women, due to their smaller size, it is between 56 and 31 ounces (average 44) or about 12 per cent lighter than in man.

In the smallest gorilla the brain weighs 15 ounces and in the largest 20 ounces, while the weight of the entire body at maturity varies between 200 and 360 pounds. At birth the human brain weighs between 10 and 11 ounces, or about one-fifth its size at maturity. Maximum size of the brain in man is reached at about the twentieth year, and it then slowly loses weight into old age.

"Identical in the physical processes by which he originates — identical in the early stages of his formation — identical in the mode of his nutrition before and after birth, with the animals which lie immediately below him in the scale — Man, if his adult and perfect structure be compared with theirs, exhibits, as might be expected, a marvelous likeness of organization. . . . A century of anatomical research brings us back to [Linnæus'] conclusion, that Man is a member of the same order as the apes" (Huxley).

Men of the Old Stone Age

The time of the Old Stone Age is that of the later Pliocene and most of the Pleistocene. Everywhere the men of this time were fierce hunters and makers of but the crudest of stone implements.

Implements. — In many places have been found large and small stones, chiefly of flint, that have rudely chipped edges and resemble

Fig. 393. — Two primitive Paleolithic flint implements associated with *Eoanthropus*. Each shows a coarsely flaked face and a simply flaked face. After Woodward, from British Museum Guide.

weapons made by primitive man. These are known as *eoliths*, "dawn stones." There is now no doubt about man-made eoliths and evidence of man-made fires occurring in the Upper Pliocene strata of southeastern England (Foxhall, Ipswich, Suffolk). Younger

eoliths, of the First Glacial time, occur at Cromer, Norfolk. These are older than the oldest known human bones.

The oldest well made human implements are known as *paleoliths*, and among these the older ones are very crude in workmanship (Fig. 393). They are nodules of flint, reduced to the required shape and size by means of oblique blows delivered to the right and left. For the greater part they are rude scrapers and knives. Although none of them appear to be weapons of the chase, their makers, the men of the Old Stone Age, were undoubtedly learning how to hunt animals for food and how to defend themselves by their greater skill in the invention and use of improved killing devices.

Fig. 394. — Profile view of the head of *Pithecanthropus*, the Java ape-man, after a model by J. H. McGregor. From Osborn's *Men of the Old Stone Age* (Scribner's, 1915).

A human chronology based on the state of the stone culture can not, however, be expressive of a correct human progression, since the Tasmanians when discovered were making Paleolithic implements, while the North American Indians had tools of a still better type (Neolithic), and their discoverers had advanced into a high stage of civilization. Therefore, long after some of the ancient hunters were making paleoliths, others remained in the Eolithic stage. The makers of paleoliths also learned to make implements and ornaments out of bone and horn.

Java Man. — The oldest known remains of fossil man himself were discovered in 1891 at Trinil, Java, together with those of many kinds of animals which are now extinct in that region. The geologic age of the fossils is somewhat uncertain, but the man of Trinil is thought to have lived during the first or second time of glaciation in Europe (earliest Pleistocene).

The human remains consist of the upper part of the skull, or cranial vault, three molar teeth, and the entire left femur. Dubois, the discoverer, named this human being *Pithecanthropus erectus*, which means *the ape-man who walked erect* (Fig. 394). The skull is of the long-headed type, and has a low crown with prominent brow-ridges, the forehead is more receding than that of the chimpanzee, and the volume of the brain cavity is approximately 28 ounces. *Pithecanthropus* is estimated to have stood 5 feet 6 inches high. In his mental evolution he had risen far higher than halfway between the apes and modern man, and must be included in the human family. He is probably not in the direct line to the higher types of man, but represents a specialized and unprogressive branch which became extinct in the Pleistocene.

Piltdown Man. — The oldest known remains of the human family in Europe, the " dawn man " or *Eoanthropus*, were found in 1913 in the plateau gravels at Piltdown, Sussex, England. The fragments, which include important parts of a skull and jaw, have been carefully set together and the entire head restored by Smith Woodward of the British Museum. The lower part of the face is decidedly prognathous or " snouty," the forehead, though narrow, is not receding, and is as steep as in modern man, the brow-ridges are feeble, and the brain case is very thick, with a cavity content of nearly 43 ounces. The size of the brain, therefore, compares favorably with that of the average European, which has a content of about 49 ounces. The skull is low in proportion to length, and even though it is archaic, is truly human; but the chinless lower jaw, with its large canines, is distinctly simian and very much like that of a young chimpanzee. This strange creature, therefore, combines a human brain case with an ape's jaw. It was probably able to speak, though in a rudimentary fashion.

Eoanthropus was a human brute, hunting and defending himself mainly with his fearful biting mouth. He was still a primitive slayer, though keener than any of his animal associates.

With *Eoanthropus* were associated very ancient types of Paleolithic implements (Fig. 393). The age of the plateau gravels is thought to be of the second interglacial warm time, when the hippopotamus lived in England; this is about early Middle Pleistocene.

Heidelberg Man. — In 1907, at Mauer, Germany, not far from Heidelberg, there was found a well preserved human jaw with all of the teeth. It was buried about 80 feet beneath the surface in river-deposited sand of early Middle Pleistocene age and possibly of the second interglacial warm time (Fig. 389). More recently

eoliths have been found in the same stratum that held the jaw. The teeth, while powerful, are distinctly human, but the jaw bone is massive and broad and clearly more like that of an anthropoid ape. This man, known as *Paleanthropus heidelbergensis,* had no chin and was probably most closely related to *Eoanthropus.*

Neandertal Man. — In 1856 most interesting human remains were found in the little valley known as the Neandertal, lying between Düsseldorf and Elberfeld, Germany. Since then, remains of many, men, women and children of this Neandertal race have been found in caves and rock shelters in Belgium, France, Gibraltar and Croatia. Their implements, however, are found scattered throughout western Europe and eastward into Poland, the Crimea and Asia Minor. In France these people are known as the Mousterians, and they are thought to have been the first who dwelt in caves. They lived during the last glacial episode when the climate was cool and finally cold, a time estimated to be anywhere from 60,000 to 150,000 years ago (Fig. 389). It was the time of the bison, horse, reindeer and mammoth, on all of which the Neandertal men subsisted. The race lived for a long time geologically.

The Neandertal people (*Homo primigenius*) were a savage-looking race of stout build, averaging about 5 feet 3 or 4 inches, with legs slightly bent at the knee, and with disproportionately large heads. They made fairly good stone implements and also knew how to kindle a fire, for hearths occur in their cave abodes. The brain was unusually large, the average capacity of Neandertal skulls being apparently 49 (in one it is 53) ounces. This average is, therefore, greater than in the Australians and about that of Europeans.

In at least two cases the skeletons were found in their original burial places, and from them we learn that they were laid away with their implements, paints and food, indicating a ceremonial interment and offerings of food and implements to assist the departed in the spirit world.

Men of the New Stone Age

We are now to take up for study the dawn of human civilization, which began roughly about 18,000 B. C., in Asia Minor, Arabia and Persia. The Neolithic people of the city of Susa, Persia, appear to go back to 16,000 B. C., and the mid-sea peoples of Crete in the eastern Mediterranean to about 12,000 B.C.

The New Stone Age of human development emerges in latest Pleistocene time and continues into historic times. The stone culture is improving rapidly and is called *Neolithic,* since the chipping of the

flints is of the highest excellence, and in addition, many of the weapons and tools are rubbed into shape and often polished. In the Neolithic period, next to food and clothing, the most important object to the men of the New Stone Age was flint. Flint mines were to them what iron mines are to us.

The people of the New Stone Age began to make pottery and introduced the herding of cattle and communal life. Later on, permanent habitations in stone huts and skin wigwams, along with agriculture, became more general, and their pottery was made more and more on the potter's wheel. Finally the metals copper, gold and iron were introduced. Definite migrations and warfare began also with these people, and manufacturing and trading as well.

Aurignacian Man. — The oldest known Neolithic peoples (*Homo sapiens*) were at first still hunters, but had far greater skill in the making of stone and bone implements than did their predecessors, the Neandertals, whom they dispossessed. They appeared in western Europe at about the close of the Glacial Period, or about 17,000 B. C. These people, the Aurignacians, came from the east, spreading westward from Asia Minor, and their remains are found throughout the great part of western and central Europe and most of the Mediterranean countries.

The Aurignacian races appeared throughout Europe at a time when the climate was colder than it is now. The animals of the chase living at that time were largely the reindeer and horse, and it is also spoken of as the epoch of the reindeer. The Aurignacian implements are of the late Paleolithic type, but the workmanship of the flints is better and constantly improves with time, and the race had many more kinds of tools to serve more purposes. They also used bone for awls and ivory for skewers and ornaments, and made spears, bows and arrows, and fur garments. Themselves they ornamented with marine snail shells derived from the Mediterranean and the Atlantic, with fossil shells from far inland places, with teeth of mammals, and even with those of human beings, and later with beads, bracelets and other objects manufactured out of shell and ivory.

Armed with better weapons of the chase and a wider knowledge of their use, the Aurignacians were able to take better advantage of their environment. Under these circumstances, they had more ease and time for reflection, and we witness in them the birth of bodily adornment, clothing and the fine arts. Their achievements along these lines excite the wonder and admiration of all anthropologists. Sculpture and drawing appear almost simultaneously, and

later comes painting. This art we find preserved in the caves of France and Spain (see Fig. 395).

Magdalenian and Later Races. — The Aurignacians were followed by the Solutreans and Magdalenians, whose history goes back perhaps 10,000 years, earlier than the most ancient monuments of Egypt or Chaldea. They, too, were hunters, lived in wigwams, and herded cattle, sheep and goats, and somewhere about this time farming of plants for food had its origin.

During the later part of the New Stone Age, the climate moderated and became moister throughout Europe. This was the time of the Azilian peoples. With this climatic change, the reindeer, the main source of food and clothing for man, vanished from all of southern Europe and retreated farther and farther northward as the continental glaciers melted away. Man also spread northward, following the reindeer, arriving in Denmark about 12,000 B. C., and in Sweden about two thousand years later.

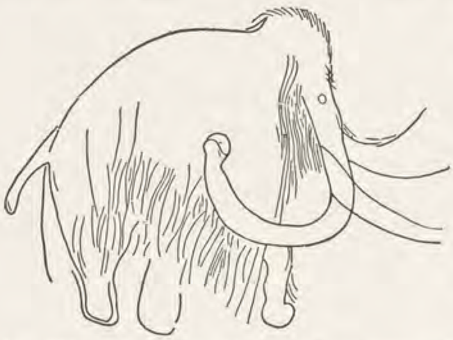

Fig. 395. — Painting of mammoth on cave wall at Combarelles, France. From George Grant MacCurdy.

Man in North America. — Many times during the past fifty years have the remains of fossil man been found in such geological associations as to lead their discoverers to assert the presence of man in North America, if not actually in the Pleistocene, at least in strata some thousands of years in age.

Mexican archeologists and geologists have long been calling attention to the occurrence of skeletons of man and something of his culture buried beneath from 15 to 30 feet of lava at San Angel, a southern suburb of the City of Mexico. These lava flows are believed to have taken place not less than 2000 years ago and the lower one may have occurred even 10,000 years ago. To the northwest of the same city the identical culture is found beneath from 10 to 12 feet of sediments. The Aztec culture, on the other hand, is modern, since it occurs above the two lava flows and in the soil.

In 1916, Sellards reported the finding of human remains along with bits of pottery and charcoal at Vero on the Atlantic coast of Florida. The associated plants, though of living species, appear to indicate that the man of Vero is but a few tens of thousands of

years old. The mammal bones, however, which are all of extinct Pleistocene forms, and presumably of a warm climate, seem to point to a far greater age.

Still other evidence appears to place beyond doubt the probability that the mound-building Indians and the cold-climate mastodons and elephants lived together in North America not so very long ago. On the basis of the annually layered brick clays of the Hudson and Connecticut valleys, it would appear that this time dates back somewhere between 15,000 and 5000 years.

Résumé

We have seen that the ape-man *Pithecanthropus* was in existence in the earliest Pleistocene, a time estimated by geologists to be somewhere between 400,000 and 1,400,000 years ago. As the true eoliths, however, are of human workmanship, they are evidence of man's greater antiquity in western Europe, where he has been since late in Pliocene time.

About early Middle Pleistocene time, human bones are again in evidence, first in Germany in Heidelberg man, thought to be in the direct line with living men (*Homo sapiens*), and secondly in the dawn man (*Eoanthropus*) of England, who is not in direct ancestry with the men of the present. Later than either of these ancestral men are the Neandertal people, who are also not directly related to *Homo sapiens*. They made their appearance probably 150,000 years ago and lived almost into modern times. As early as late Pliocene time, man in England knew how to kindle fire. The Neandertal men also made fires, and had a religious instinct. With the appearance of the Aurignacians about 20,000 years ago, modern men are at hand, while human society and primitive farming had their rise about 10,000 years ago.

Human mentality now dominates the organic world, and to it all creation will soon be more or less subservient. Through his inventions, man will eventually control his environment and largely nullify the laws of natural selection and survival of the fittest to which all other organisms are subject. His future progress, however, is dependent upon himself, dependent upon whether he will learn to control himself for the benefit of human society.

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